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The Institution of Electrical Engineers.

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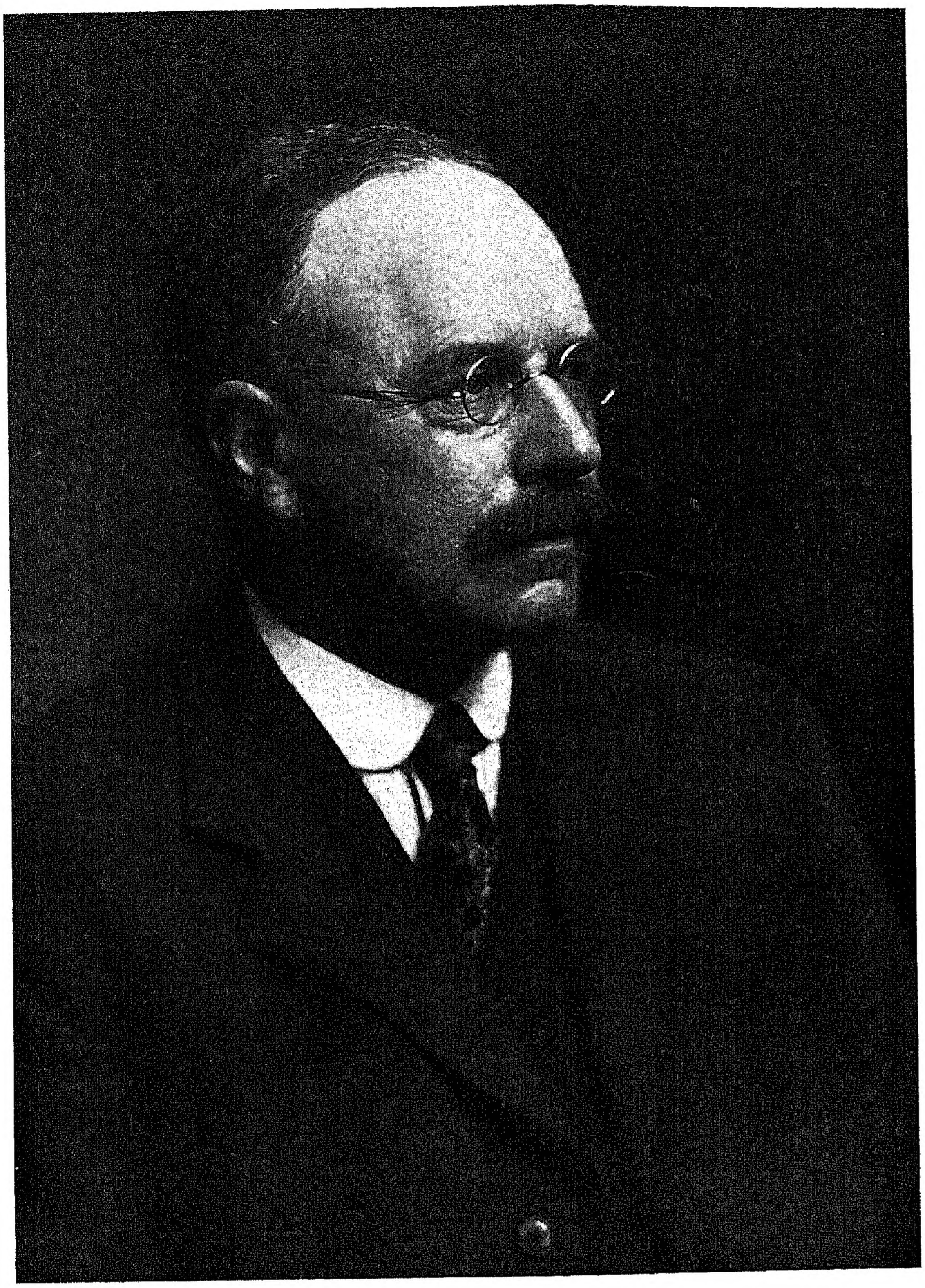

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THE JOURNAL OF

The Institution of Electrical Engineers

VOL. 72.

INAUGURAL ADDRESS

By Professor E. W. MARCHANT, D.Sc., President.

(*Address delivered before* THE INSTITUTION, *20th October*, 1932.)

I wish first of all to thank you for the great honour you have done me by electing me as your President. It is a very great responsibility to follow in the footsteps of the many illustrious men who have occupied the presidential chair.

The Institution is now one of the largest engineering societies in the world, and its interests are so widespread and concerned with so many branches of industry that it is impossible for any one man to represent it adequately. Although, from the personal point of view, I think that your choice may be misguided, it is a great satisfaction to me that the Institution has recognized the part which universities and technical colleges are playing in the training of electrical engineers.

Most of you have passed through the perils and adventures of a college course, and it is evidence of your charity and good nature that you have been willing to elect to the presidential chair a member who will recall to your minds what must seem, to some of you, one of the most strenuous, but, I hope, also one of the happiest, periods of your life. A professor should represent the harmony between theory and practice in the science of engineering. In a thesis which he wrote, MacQuorn Rankin—the first professor of engineering in the University of Glasgow and one of the greatest teachers of his time—divided science into three compartments, with pure science at one end, applied science at the other, and the student and professor in the middle, the last-mentioned maintaining communication between the two ends and deriving from the results of the theoretical researches of the physicists those rules and formulæ which are the working values of the practical engineer. Many of the results of pure science have undergone such a transformation that, as Prof. Barr said in his address on Rankin, many may not realize that "familiar and almost primitive as some of these rules may seem to-day, they had to be quarried out of the formless mass of the unknown by the patient labour of a master craftsman." Such was the work of the pioneers of engineering teaching, and it is well to remember that the electrical industry has been created as the result of the investigations of pioneers whose researches, in their day, were thought by most people to be of no practical importance.

INTRODUCTION.

The status of any profession depends to a very large extent on the character of the education which its members must receive. It is not many generations since the profession of the surgeon was looked on askance. The surgeons of earlier days performed operations in the spare time that was available after fulfilling their ordinary duties as barbers. Even the younger professions were held in relatively slight esteem until the system of training required for membership of them had become well established. In this connection I should like to quote from an Address on "The Coming Generation" recently published by Sir John Russell, the Director of the Rothamsted Agricultural Experimental Station.

"It is a common complaint that the scientific worker is made subservient to the business organizer and administrator. That will always be likely to happen unless the scientific worker manages to secure a decent education, otherwise he will inevitably become simply a technician, working in a laboratory overall instead of a workshop overall, but simply taking the place of the old craftsman. The remedy lies in our own hands. It is to discourage early specialization at school and exclusive specialization at college. To insist, instead, at any rate that the higher degrees in science should connote a good level of general education."

What Sir John Russell says about scientific workers is equally true of electrical engineers. The profession of medicine, however, is esteemed not entirely because of the elaborate training it entails or because of the money that is made by those who practise it, but mainly because of the service it renders to the community. In this respect the electrical engineer can claim at least equality with the medical man.

The conditions of life in civilized countries have been vastly improved during the last 20 or 30 years by the work of electrical engineers. To take only two examples: how greatly have the improved lighting and ventilation of factories due to the use of electricity reduced the number of accidents and improved the health of the workers; and how much has the introduction of broadcasting increased the amenities of life in our country-side and in those distant parts of the world to which many of our countrymen have migrated.

This Institution is the youngest of the engineering institutions, and it has always been catholic in its sympathies and democratic in its recruitment. It has always welcomed to its membership anyone who has been able to show that he is a competent electrical engineer. The policy adopted by the Institution has been amply justified by the success which it has achieved; for to-day, with nearly 15 000 members, it is the largest engineering institution in this country, and it stands as high as ever it did in scientific prestige. Our *Journal* compares favourably, I think, with that of any other engineering body, both from the point of view of the standard of its contributions and from the breadth of its interest.

Training of Electrical Engineers.

The old public-school tradition, that a classical education is the best for everyone, has died hard, and I believe that even to-day there is a considerable body of schoolmasters who maintain it. In education it is the method that matters most. Provided suitable methods can be devised for teaching scientific subjects, it stems only common sense that the prospective engineer should spend some of his time at school in studying the fundamental sciences underlying his future occupation. Premature specialization with a view to vocational training is, however, a great mistake. The specialized instruction is very often not used because the boy does not take up the branch of work for which he has been trained, and, where too much time is spent in specialized instruction, this is bound to lower the standard of general education which it is important that every electrical engineer should have if he is to hold his own in the world.

The most striking changes in the educational system of this country during the last 30 years have been the establishment of a large number of State-aided secondary schools and "junior" technical schools, and the establishment and growth of the newer universities, the latter being State-aided also to a certain extent as regards maintenance, whereas the capital outlay has been provided almost entirely by private munificence.

At the present time the educational ladder has been made, if anything, too wide in its lower rungs. Nowadays any really able boy can obtain, without serious difficulty, all the education of which he is able to take advantage. The chief criticism that can be made of the educational system for engineers, as it exists to-day, is that throughout the country there are too many places of instruction, technical schools, and colleges, which are trying to reach an unnecessarily high standard. Almost every teacher in a technical school rightly encourages his students to reach a high standard of professional knowledge. If, however, a student is to receive the instruction needed for the profession of an engineer, it is essential that he should have at his disposal machinery and apparatus which only a relatively small number of colleges can afford to provide, and it is much better that he should receive his training in an institution which is well equipped for the purpose and in which there are enough students of proved ability to ensure vigorous competition. A considerable economy could, I believe, be effected in technical education by centralizing the higher branches of instruction in a smaller number of centres.

The system of training engineers in evening classes has produced some excellent results. Some of our ablest engineers have been trained in this way, and there is a great deal to be said for the combination of practical work and scientific education which such a course entails. At the same time the number of people who, after they have been fully occupied in the daytime, can take advantage of evening-class instruction must always be relatively small. It requires high qualities, both mental and physical, to do so, and I am sure that a good many of those who have passed through the mill would have received greater benefit if they had had more leisure to assimilate the ideas and principles which were put before them. The part-time day course is a great improvement on the evening course.

During the last 35 years there has been a great increase in the equipment of electrical engineering laboratories. If a laboratory only provides a well-organized set of rigid exercises it is a dead and uninspiring place for a budding engineer. Although it may be necessary, when handling large classes of students, to organize the instruction by pushing students through a rigid course of training, such a procedure ought not to be adopted in a college which sets out to produce the best type of scientific engineer.

The interest of electrical engineering lies in the fact that an electrical engineer has continually to solve new problems. His work, except in the early stages of his career, cannot be entirely routine. If it were, a large part of the training which is given to engineers might well be saved. He has to be ready for emergencies, whether in dealing with clients or in overcoming the practical difficulties that arise in the practice of his calling. If he is to be efficient, he must not only understand what he is doing, but also understand the principles of action of the machines and apparatus which he is using. He must have an open mind, he must be able to observe, and he must be able to draw conclusions from his observations; in other words, he must be able to think. Any engineering training (or, in fact, one may say any education) which tends to develop memory and the mere acquisition of a knowledge of facts is bound to fail. That system has been in operation in China for countless generations with results that we all know. It is not education, as we define the word.

What then must be done if the desired result is to be achieved in the trained man? He must be taught in such a way as will enable him to develop his natural powers, and he must be encouraged to use his creative instincts. That was one of the subjects on which the late headmaster of Oundle School, Mr. Sanderson, laid most stress, and a relatively high standard of scientific

work was attained in his school laboratories by encouraging the creative instincts of his boys. A good many people think that his method is unsuitable for all but a relatively small number of exceptional boys, but the method is one which undoubtedly ought to be applied to the selected people who take up any scientific calling. If they are not capable of profiting by this system of training, they will never get very far beyond the lower rungs of the ladder of the engineering profession.

Development of initiative and thinking power is the principal end to which the scientific training of an engineer should be directed. This may be assisted by giving the student, in the later stages of his training, some definite task to accomplish, either a definite piece of experimental work in the laboratory or the design of a machine or a piece of apparatus, or a report on some problem which an engineer might be called upon to solve. The system of reports originally introduced, I believe, by my old professor, Prof. Ayrton, at the Central Technical College, was most beneficial. It is by methods like these that the latent capacities of a student can be stimulated and the best training given.

There is, however, another principle which it is important should be instilled into the engineer—here, again, I pay tribute to what was laid down by Mr. Sanderson—and that is the principle of co-operation. One of the most valuable parts of the training of a man in college is that gained by working in co-operation with his fellow-students. No man to-day can be a pure individualist; he has got to recognize that in the modern world he must work with others. During his course at a college or university a student must co-operate with others, for example, in the college societies and in the groups which are formed in the laboratory for carrying out experiments. This is not the least valuable part of the training which he undergoes.

One of the problems with which a professor has to deal is the placing of men in industry when they have completed their college courses. It is sometimes difficult to forecast the career which a student may ultimately adopt. In my own experience, one man who started as a "light-current" man is engaged in the electrification of railways in South America, and the chief engineer to the South African Government (who corresponds to a member of our Central Electricity Board) wrote in his early days a valuable book on thermionic valves. Breadth of engineering training therefore is essential. To-day a large proportion of electrical engineers are engaged in the distribution of electrical appliances and electrical energy. The electrical engineer in charge of a large undertaking has to concern himself mainly with the financial and administrative side of his business, and it is therefore becoming increasingly important that all engineers should have some knowledge of the fundamental principles of finance and economics.

I should like here to pay tribute to the invaluable help given to many educational institutions by leaders of industry. An Advisory Committee is a very valuable asset to any institution engaged in the education of electrical engineers. Liverpool University was fortunate when, at the start of its Engineering Faculty, we were able to secure the advice and help of eminent engineers, who gave us much assistance in organizing our courses of training. An Advisory Committee is also of especial help in arranging for students to visit local works during vacations, and in making suggestions as to ways in which the practical facilities which are available in the district can be utilized to the best advantage. During the last 10 years our Advisory Committee has been of great assistance in making arrangements for vacation work for students in training, and for special lectures, and in interviewing, at the beginning of their last year, the students who are going through their courses at the university. A committee of this kind, which is a link with practice, is also of great value during discussions of syllabuses and possible new subjects of instruction.

In the training of engineers there is always conflict between the academic and the practical sides. The engineering student should be directed along a middle path. From the academic side it is of importance that he should be given a good education, and from the practical point of view it is important that the education so given should have as close a relationship as possible to practical work. In this connection I should like to pay special tribute to the advice and help we have received from many well-known engineers.

Examinations.

I have served for many years as a member of the Examinations Committee of the Institution. No one who has been concerned with examinations wishes to put too high a value on them. We all know the weakness of the examination system. We all know the way in which examinations can be passed by cramming, either from textbooks or with the aid of a skilful crammer, and many educationists would like to see something other than an examination to test their products. But requests for the suggestion of an alternative have never produced an effective one. After all, what is an examination? It is an endeavour on the part of the examiner to find out what the candidate knows; and the only way of doing that is to ask him questions. An examination tests the ability of a candidate to answer questions on the theory and practice of his calling. An examination is also a test of acuteness of mind. A person who is not able rapidly to come to a conclusion will find it difficult to answer an examination paper. Quickness, although it may not be the most essential, is a very valuable quality in an engineer. What an engineer needs, however, more than quickness are accuracy and judgment; but these are qualities which are also tested by an examination.

Examinations are—and I think quite rightly—regarded as essential for determining the eligibility of candidates for membership of the Institution. They can never be more than a preliminary test. The real qualification for an electrical engineer is his ability to do his job in the branch of work in which he is engaged, and the Membership Committee necessarily attach great importance to the experience of a candidate for corporate membership. At the same time, adequate knowledge of the principles underlying the operation of the machinery and apparatus which an electrical engineer has to handle is as essential to him as a knowledge of the structure and behaviour of the human body is to the doctor, and it is with the testing of this knowledge

that the examinations are concerned. There are many avenues by which that knowledge can be gained, and it is not for me to say that one is better than another.

National Certificates.

I should like to refer, however, to the National Certificates in Electrical Engineering which are now issued under the joint authority of the Board of Education and the Institution. I think it is not too much to say that the National Certificates have effected a great improvement in the theoretical training of those engaged in the practical work of the industry. The scheme was intended to take the place of the older Science and Art Examinations, certificates for which were issued from South Kensington. It has encouraged a large number of evening-class students to continue their technical education. The principle that has been adopted for the Certificate examinations has been the setting of papers jointly by the teacher and an external assessor, whose function it is to ensure a satisfactory minimum standard. When dealing with an advanced subject there is a great deal to be said for this system, since the scope of the work that can be covered in any one place is limited; but for the early stages and the principles of a subject there is, I think, a good deal to be said in favour of a uniform examination. The task of assessing some 150 different papers in elementary electrical engineering in order to secure a definite minimum standard of knowledge for a certificate is one of great difficulty, and it is doubtful whether anything is gained by having papers set in such profusion. The Higher National Certificate has been recognized as exempting, with certain limitations, from parts of the Institution's Graduateship Examination and I feel sure it will help a number of valuable potential members to qualify for membership.

Scholarships.

One of the Institution's activities which is of long standing, and which has recently developed rapidly, is the award of scholarships. The method of making the awards is one which might well be adopted by other bodies.

The Committee of Award not only take account of a candidate's record as an examinee, but also interview him and award marks for personality and his prospect of success as an engineer from the personal side. Although, as I have indicated, success in examinations is not necessarily a test only of memory, the Institution recognizes the limitations of such a test. An interview by men of experience is one of the most effective ways of judging a man's capacity; and it is a valuable feature in the training of engineers to let them become accustomed to an interview.

In some colleges it is customary for a student, towards the end of his career, to have a formal interview with an eminent engineer, who discusses with him his hopes as regards a career and who attempts to weigh up his potentialities in the field of activity which he has chosen. Such a scheme is of the utmost value, especially to students whose knowledge of the world is limited, and it enables such students to improve their chances of selection in any competition for a vacancy.

One of the most valuable of the Institution's scholarships, the Ferranti Scholarship, is awarded, however, to a man who has completed his college course, in order to enable him to continue his training as a research worker. The Institution has always recognized the importance of research work and took a large part in the setting up of the Electrical Research Association.

Research.

Engineering research to-day is costly, and it is inevitable that the engineering departments of the universities should confine their research work to the more fundamental aspects of applied physics. The carrying out of investigations on full-size apparatus has to be done in the research laboratories which nearly every progressive engineering firm has established for the purpose.

An estimate was recently published of the saving to the industry which has been effected as a result of the work of the cables research committees of the British Electrical and Allied Industries Research Association. This showed that the annual saving is many times greater than the whole cost of the investigation. Under efficient direction a research laboratory is one of the most valuable assets of any industrial undertaking. It is impossible to estimate its financial value exactly. The names of Faraday, Kelvin, Maxwell, Lodge, Hertz, J. J. Thomson, Rutherford, Parsons, and many others, bring to mind the incalculable benefit which research has conferred upon engineering. Electrical engineering is the creation of scientific research. It is well, therefore, that the Institution should encourage it by every means in its power. It is one of the most important duties of a university department to help in the training of research workers, and I should like to pay tribute to the value of the help which has been given by the Department of Scientific and Industrial Research during the last 12 years in this connection. The maintenance grants which have been awarded to specially selected research students have enabled a considerable number of men to be trained as research workers who could not possibly have afforded to remain at the university unless some such help had been given; and nearly all of the men who have been so trained in electrical engineering laboratories are now engaged on research work in industrial research laboratories.

Research in electrical engineering is limited by the kind of instruments that can be used for carrying it out. It is only when special instruments have been designed that research along certain lines becomes possible. I consider that no part of the training of a research worker is more important than that of designing the apparatus which will enable him to carry out an investigation.

The making of tests with suitable instruments is all very well, but if a research student has had to construct, during the course of his investigations, the apparatus with which he makes his measurements, he has done something that gives him confidence in himself and a more complete knowledge of the phenomena which he has observed, than could have been obtained in any other way. As Mr. C. C. Paterson pointed out in his Presidential Address two years ago,* it is the scientific method applied to nearly all the problems of the day

* *Journal I.E.E.*, 1931, vol. 69, p. 1.

which will lead ultimately to their effective solution. It is a study of the causes of trouble that is needed, and I think that is true in the economic and social field as much as it is in science.

Psychology as a subject of research for engineers is comparatively recent; but one of the most interesting results of our war-time experience was the development of methods of choosing the men who were most suitable for the different kinds of work which they had to perform. For example, I remember very well the early days of listening for submarines. Direction-finding gear was used which, in its early form, consisted of two hydrophones containing receivers supported on a frame which could be rotated about a vertical axis, these receivers being connected to two head telephones, through which the observer could listen to the noise. It was found that, by rotating this framework, it was possible for an observer to determine the direction from which the sound was proceeding. When this arrangement was first put on board a trawler, the man chosen to work it was the least competent sailor, the one who could be spared most easily for odd jobs. As the result of careful observations it was discovered that only 2 or 3 per cent of the recruits to the Navy had the sense of direction highly developed and could determine with accuracy the direction from which a sound was coming. After this had been discovered, almost entirely as a result of the initiative of Mr. A. P. M. Fleming, the choice of observers was made in a very different manner. The men were selected for their ability as sound direction-finders, with the result that the whole system of location by sound became much more accurate and reliable.

There are many other jobs in engineering where similar methods may be and are being used, especially in the more mechanical processes which are common in any works. Mr. Paterson suggested during his year of office that we should open our doors to enable physicists to become members of the Institution; and many have already taken advantage of this opportunity. It does not seem unreasonable, therefore, that we should also open our doors to one or two psychologists!

Electrical Measurements.

As I have already said, the interests of the Institution are so wide that it is impossible for one man to deal with all of them. There is one branch of electrical engineering, however, about which I may perhaps be allowed to say something, because it is one in which I have taken a great interest for many years; and that is the measurement of electrical quantities. The Institution has recognized its importance by establishing a Meter and Instrument Section.

The importance of accurate measurement can hardly be exaggerated. It is only 30 years since the National Physical Laboratory was first established in this country, and it is difficult to overestimate the help which it has given to manufacturers. Sir Alfred Ewing said recently, in regard to the Laboratory: "From small beginnings it has grown to be an influential factor in the world's scientific progress and a legitimate subject of national pride." Sir Richard Glazebrook, its first director, was one of our most distinguished Presidents.

One of the men who did much work in this connection was the late Lord Kelvin. We all feel proud to remember that he was President of the Institution on no less than three occasions. Kelvin's work covered an enormous range, but, from the point of view of the electrical engineer, no part of it was of greater practical mportance than that which he did in connection with measuring instruments. He designed a great number of them.

Nowadays, accuracy has been greatly improved in the ordinary commercial measuring instruments, and the range of measurement has extended in an almost unbelievable fashion. The need for great accuracy in the measurement of large quantities of energy is of paramount importance. Some of the metering stations in connection with the "grid" are designed for 60 000 kW. With a load factor of 30 per cent and energy at $\frac{1}{4}$d. per unit, an error of one-half of 1 per cent will make a difference of nearly £1 000 per year in the revenue of the power station.

It was my good fortune to be associated with the late Mr. Duddell (who was President of this Institution from 1912 to 1914) in the development of the oscillograph. We thought, at that time, that we were doing rather well in recording alternating currents which were varying 50 times a second. Nowadays it is possible with the cathode-ray oscillograph to photograph currents which are changing millions of times a second. We can trace the changes of voltage in a cable which are produced by a surge that travels backwards and forwards along it. That has opened a field of research beyond anything that was dreamt of 20 years ago.

The large-scale development in the use of electricity and its transmission over long distances has made it necessary for much more careful consideration to be given to the effect of surges on distribution and transmission lines. It is important also to know the properties of insulating materials when subjected to high-frequency stresses such as are produced by high-frequency surges. In this connection I should like to consider the change in outlook on electrical problems that has been brought about by the surge method of dealing with them. It is a change which is fundamental and which must be ascribed to our first Faraday Medallist, Oliver Heaviside; for it was he who worked out the mathematical solution of the surge problem. The surges do not last very long. As a rule, everything is over in 1/100 000th of a second.

Incidentally, this problem brings out the importance of mathematics in discussing electrical problems. It was the mathematician who first introduced us to it. The mathematician was able to calculate the magnitudes of the voltages and currents which occur when a surge takes place.

I may, perhaps, illustrate my point by taking as an example a circuit containing two wires (each, say, a single 0·064 in. copper conductor) parallel and near to each other (say, 5 cm apart) to which is applied an electromotive force from a primary battery. The current from the battery is given by E/R, and we generally assume, if the wires are very close together, that the current instantly rises to its full value. If we look at this circuit from the Heaviside point of view, the growth

of current in it becomes something quite different; we are dealing with what happens in the circuit during the first 10-thousandth of a second after the switch is closed. What happens when the battery is applied?

As soon as connection is made, let us say by a double-pole switch, a surge of current flows along the wire, the value of the current being given by $E/\sqrt{(L/C)}$ where L and C are the inductance and capacitance respectively per unit length of the wire. The value of this impedance $\sqrt{(L/C)}$ will be about 500 ohms, so that if we use a 10-volt battery there will be a momentary surge of current of the order of 1/50 ampere. This surge will flow to the far end of the wire at a speed approximately equal to the velocity of light, that is, it will travel from the battery to the other end of a wire 30 m long in one 10-millionth of a second. Then the surge will be reflected, the current through the wires will be doubled in magnitude, and we shall have a total current of 2/50 ampere. This will take one 10-millionth of a second to return to the battery end. When it reaches the battery the current surge is reflected once more, and during the next 10-millionth of a second the current flowing along the wire will be 3/50 ampere, and so the process is repeated, the current being built up by the passage of these surges until it reaches its steady value. The wire has a resistance of 0·5 ohm and the steady current will be 20 amperes, this value being attained after the surge has travelled backwards and forwards about 1 000 times. This will have happened in 100 millionths of a second, and for practical purposes it does not produce any appreciable effect in a simple circuit such as I have been discussing; but if we are dealing with cables, then the passage of this current backwards and forwards along the cable may give rise in the dielectric to high-frequency voltage stresses, which will tend to break it down.

In practice, surges may be produced in a number of ways—for example, by the blowing of a fuse, or a flash-over on an overhead line—and travel from the point where they are created; and when the constants of the circuit through which they are passing change, they may be reflected or may continue with increased amplitude. Experimental investigation of these surges has become possible through the improvements that have been made in the cathode-ray oscillograph, and I am indebted to Dr. J. L. Miller, an old research student from Liverpool, for an oscillogram (shown on the lantern slide) that has been taken of a short surge transmitted backwards and forwards along a short length of overhead line. The whole time taken to make this observation is less than one millionth of a second, and you will see on the record traces of an oscillation having a frequency of 35 million cycles per second.

Development of Heavy Electrical Engineering.

During the forthcoming session the grid, which has been in course of construction for the last four or five years, will be practically completed. The original 8-year programme has been cut down by two years, and I think that the engineers and all concerned with the grid are to be congratulated on the rapidity with which their schemes have been carried out. The next stage may be called the "trading" stage in the development of the use of electricity; and, if progress on this side is made with the same speed as that which has marked the development of the grid itself, Great Britain will soon be completely electrified.

The supply of electrical energy to the consumer may be divided into three stages: its generation, its transmission, and its distribution. In former times great importance was attached to the generation of electrical energy and to improvements in the efficiency of the machines for producing it. This problem is still urgent and is engaging the attention of many engineers, but it has so progressed that the range of possible improvement in the design of electrical generators and transformers is small.

A great deal of attention has recently been paid to the transmission of electrical energy from the central stations to the distributing points, and here again great improvements have been made. Improvement in the technical design of transmission lines, from the point of view both of efficiency and of reliability, has been rapid, and engineers have studied this problem also with a view to reducing both the cost of the line and the losses in it.

One of the most interesting developments recently published has been the description of the transformation of direct current into alternating current by means of gas-filled relays; and tubes have already been constructed capable of dealing with powers of 1 500 kW. These discoveries open up possibilities for the use of direct current at high voltages for transmission, which will increase 6 or 8 times the carrying capacity of the overhead lines already constructed. There is not enough information available of the cost of these relays to determine whether they are economically practicable. In a paper published about three years ago I pointed out that the cost of the electrical method of transmitting energy under modern conditions was very nearly the same as the cost of carrying the coal which produced the energy. If these developments fulfil their promise, the electrical transmission of energy will be substantially cheaper than the carrying of coal.

We are still left with the final stage of the problem, namely, the distribution and utilization of electrical energy, and to-day this side of electrical engineering offers more scope than any other. In a report recently published by the Central Electricity Board it was pointed out that less than 30 per cent of the population of Great Britain had the advantage of an electric supply, and that only 65 per cent of the power utilized in factories was produced electrically. The availability of an electric supply throughout the country, made possible by the building of the grid and its associated distribution points, will open up great possibilities for this branch of electrical engineering during the next few years, but if progress is to be rapid much education of the public in the use of electricity will be required. The Institution has done yeoman service in this direction by its Faraday Lectures, which have given large numbers of people a knowledge of electrical apparatus and of the fundamental principles involved in its operation. This has undoubtedly helped to accelerate electrical development.

One of the most useful things which has been done

in Germany has been the installation in all schools of electrical laboratories, which have been equipped by the electrical manufacturers, at a relatively low cost, with a great variety of electrical apparatus, heaters, cookers, irons, kettles, etc. The object of these laboratories is to familiarize the boys and girls with the use of electrical appliances, and I think that there is no better way of advertising the advantages of electricity. In the domestic field we have to thank the Electrical Association for Women—and Miss Caroline Haslett, in particular—for much useful propaganda. I think they can help forward more than any other body the development of the domestic uses of electricity.

Ten or twelve years ago I had the pleasure of visiting, as a member of the Institution delegation, a number of Dutch towns and villages. One of the most interesting of these visits was to some farms not far from Groningen in which electricity was being used for all kinds of purposes such as milking, lighting chicken-houses and cow-sheds, cutting chaff, grinding corn, raising fodder to the roof of a barn by a small conveyor, and in many other ways. Nowadays the use of electricity in agriculture is coming into its own domain in this country, and there is, I believe, a great future for it.

During last year we saw many demonstrations of what flood-lighting can do to enable us to appreciate the beautiful buildings which are scattered all over England. Many of us did not realize the artistic treasures we possess, until we saw them lit up by the flood-lighting which added so much to their beauty. Why should not this practice be regarded as a national service, so that everyone can learn to appreciate good architecture? Hours of darkness are not all spent in sleep. They need to be beautified just as much as the hours of daylight. What a waste of beautiful buildings if we cannot see them at night! Now that electricity is becoming available in large quantities and at a reasonable rate, the possibility of using it in this way is becoming a matter for serious consideration.

We have heard both in England and in Holland of new developments in highly-efficient gas-discharge lamps yielding 4 or 5 candles per watt. The fact that two different advances along the line of the gas discharge should arrive almost simultaneously, shows what promising possibilities this form of lighting seems to have. Even if the proposal to light the arterial traffic-routes in such a way that car headlights can be dispensed with is not realized in the near future, we are undoubtedly seeing the beginning of a form of electric lighting to the possibilities of which our present knowledge of physics hardly sets a limit.

It is in electric heating, however, that there is the greatest field for development in the use of electricity. When the efficiency of power stations was under 10 per cent, as it was less than 20 years ago, electric heating and cooking were not economically practicable; but with power stations having a thermal efficiency such as 25 per cent, the question has assumed a different aspect; and when one considers the greater efficiency, the absence of fumes in the house, and the possibility of placing the electric heater where it will produce the best effect, electric heating becomes a serious rival of other heating and cooking methods, on grounds not only of economy and convenience, but also of improved health and ventilation. A great deal remains to be done in the design of efficient heating systems for buildings. The efficiency of an electric heater as an apparatus for transforming electrical into heat energy is always 100 per cent, but the great advantage of electric heaters is that they can be placed anywhere and can therefore reduce to a minimum the heat needed to give the required warming effect.

Electric Power in the Tropics.

Although there are great possibilities of development in the use of electricity in Great Britain, I should like to draw your attention to a book which is about to be published by Prof. Blacklock, one of our leading doctors in the field of tropical medicine, dealing with the great advantages which would accrue if more effective lighting and ventilating plant were available in the tropics. Those who live in this country find it difficult to realize the entirely different conditions which exist in such climates. Education in science and in its practical applications is probably one of the greatest needs to-day of the inhabitants of our tropical Dependencies, but the introduction of electric lighting and of a supply of electric power, which would enable refrigerating appliances and other electrical equipment to be installed, would be of immense value from the standpoint of health and efficiency both to the European population and to the natives.

From the economic point of view it involves a consideration of the best distribution of wealth as between primary producers and manufacturers, for if tropical countries are to have enough money to pay for this kind of development, it is essential that their products should secure a remunerative price. One of the great difficulties of the world to-day is that the primary producing-countries are not getting a fair share of the world's wealth, with the result that they are unable to purchase the manufactures which countries like ours produce. As a result, the trade of the world is much smaller than it should be.

It is the generally accepted view of most economists that an increase in the price of primary commodities would be a benefit to trade generally, and it is the only thing which would enable that development to be carried out which Prof. Blacklock has suggested as most desirable for our tropical Dependencies. There are other sides to this question, and there seems very little doubt that the incidence of disease could be appreciably diminished by suitable engineering development and by the introduction of electricity. It is a matter for discussion whether it is not sounder economically to spend money on the improvement of conditions which will reduce disease, than it is to spend large sums on a medical service whose function it is to cure disease. This is far too big a subject to discuss in an address of this kind, but it emphasizes the relation between the engineer and the doctor. If the engineer could be given a freer hand in improving material conditions in the tropics, the work of the doctors would be very much diminished, and there would be the added advantage of a population which would be normally healthy instead of one demanding continuous medical attention.

Light-Current Electrical Engineering.

It is on the light-current side that the practical importance of scientific investigation has been most evident. The telegraph became possible after Oersted's discovery of the magnetic effect of an electric current. The telephone also was a product of Graham Bell's practical scientific research. Heaviside dealt with the transmission of electrical pulses from the standpoint of the mathematician. Fleming developed the valve as a piece of physical apparatus, and nearly all the work that telegraph and telephone engineers have since done has been based on these discoveries. In the words of Sir Alfred Ewing, "it was the scientific nursing of the infant and the scientific culture throughout its period of growth that brought it to its present splendid manhood."

The transmission of a telegraph or telephone message is a special case of the surge problem, and it was Heaviside's early interest in the mathematics of this subject which led him to investigate it and which made it possible to produce the loaded cable. Lord Kelvin (then Prof. William Thomson) worked out the first practical solution of the submarine-telegraph problem and showed how the transmission of a telegraph signal could be estimated by purely mathematical calculation. It is interesting to recall that the engineers who were in charge of the first submarine cable thought that the required signal could be secured by increasing the power of the battery used for sending the message, with the result that the cable broke down and the experiments were delayed for over a year. On the other hand, as Sir Alfred Ewing has pointed out, one must remember that in radio-telegraphy it was the courage of the inventor, Marconi, which "forestalled the discovery of the Heaviside layer." Had it not been for his experiments at Poldhu, it would have been many years before world-wide radio-telegraphy could have been achieved.

It is only within the last 30 years that it has been possible to deal with electric currents in free space. When Sir Joseph Thomson first discovered the electron in the cathode ray, in 1897, the discovery marked an epoch which will always be regarded as one of the greatest in scientific discovery. During the last 10 years much attention has been given to devising the best methods of producing and controlling free electron currents, and currents of hundreds of amperes can to-day be created inside a vacuum tube. We know that these currents can be formed from any material, for the work of Sir Joseph Thomson and Lord Rutherford has shown us that all matter consists of aggregations of electrons and protons.

As electricity is the ultimate constituent of the atom, electrical engineering is therefore the most fundamental engineering of all, because it deals with the practical methods of controlling these particles. It has the whole world for its domain. The practical advances which have been made possible by the discovery of the electron and the proton cannot be forecast. Although they are becoming increasingly important in electrical engineering, the study of their structure and behaviour is still largely the domain of the physicist. The wisdom of making it easier for physicists to become members of the Institution is thus becoming more apparent every day.

It is to the lasting credit and benefit of electrical engineering that over 30 years ago the Institution, recognizing that physics was the key to its future progress, fostered the Physics Section of *Science Abstracts*. There are some who ask why electrical engineers should have the responsibility of maintaining that Section. The answer is that there is little money in physics itself. There is no "industry of physics" to take the financial responsibility for such an essential publication. It is only when physics is applied to electrical engineering that it becomes profitable and can support a publication consisting of abstracts for the assistance of workers in physics in connection with those investigations which, to-morrow, will be the newest activity of the electrical engineer.

Electrical engineering has been peculiarly fortunate owing to the fact that the industry began at the scientific end. In this respect it was not like mechanical engineering. Ohm's law was understood before a house was supplied with electric light or a factory with electric power, whereas the steam engine was invented years before the second law of thermodynamics had been enunciated. For this reason the importance of scientific study in connection with electrical matters has always been more fully recognized.

Electricity in Medicine.

There is another use of electricity in which some members of the Institution have taken great interest, namely, the use of electricity in medicine. It is interesting to recall that two of the pioneers of electrical engineering, Volta and Galvani, were physicians. Nowadays, electricity is used in medicine not only for giving therapeutic treatment, as, for example, high-frequency treatment and X-ray treatment, but it is of special value for recording the effects of disease in the human body.

Physiologists have shown us during the last half century that every muscle and nerve is the source of an electric current. One of the most powerful muscles in the body is the heart, and Dr. A. D. Waller of the University of London demonstrated over 40 years ago that the heart produces currents which can be recorded if the hands are connected to a suitable instrument. By making use of this appliance it has been possible to study the condition of the heart far more exactly than was possible to the older practitioner.

The engineer and the doctor are complementary in the sense that the more the engineer is allowed to do, the less the doctor will have to do; but the electrical engineer can assist the doctor in other ways, and in no way more than by providing the physician with appliances which will enable him to diagnose more accurately the diseases of the human body. Perhaps the most notable change that has come about during the last 35 years has been the possibility of seeing inside the human body. The discovery of X-rays marked an epoch in diagnosis and has given to the operations of the surgeon a precision which is of incalculable benefit. The link between the electrical engineer and the doctor is becoming closer, and before long we may reasonably

expect that the Institution will find it necessary to establish a section dealing with the applications of electricity in medicine.

Progress of the Institution.

The range of activity which is covered by the Institution is vast in its extent and increasing in every direction. If the Institution is to remain as the representative body dealing with the applications of electrical science in this country, it is bound to expand. Those engaged in the different branches have a common link which binds them together, but, as the complexity of the organism grows, there is bound to be more differentiation between the sections.

We have already two examples of how subdivision can benefit both the Institution and the branch of the industry with which it is specially associated. I mean, of course, the formation of the Wireless Section and the Meter and Instrument Section, and I am sure that everyone will agree that the Institution has been greatly strengthened by the establishment of these Sections. As time goes on there will almost certainly be other Sections formed, for the increasing scope of electrical engineering makes it necessary that there should be further subdivision; but I am sure you will agree that with an organic link connecting the Sections to a central body, an organism is secured which is much more vigorous and efficient than one consisting of a number of separate units. We have, I think, an admirable analogy in the British Empire, of which we are so proud. Strength is gained by co-ordination and co-operation between the different branches of that great imperial body. These strengthen each other, but if the organism is split by senseless divisions it will fail to maintain its vitality.

Co-operation Between Engineering Institutions.

It is obviously a great advantage to the electrical industry that all engineers occupied with the production and sale of electrical apparatus and electrical energy should form one great guild, i.e. The Institution of Electrical Engineers. The electrical engineer provides one of the most vital services of our modern civilization, and all engaged in this great service should work together to maintain and improve it, but I would go further and suggest that the time is not far distant when electrical engineers, mechanical engineers, and the venerable civil engineers, should attempt to form one greater guild, the nucleus of which exists already in the Engineering Joint Council.

In the universities we are faced with the problem of training all kinds of engineers in the scientific principles of their profession. When they first come to the university, all prospective engineers take a common course for one year or, in some cases, two years. They have first of all to show themselves competent to write their own language and to express themselves clearly and intelligently. That is a qualification which every educated man should have. They must be able to calculate. They must know something about the principles of mechanics and physics. These subjects are common to all engineers, and it does not seem beyond the bounds of possibility that this should be recognized by having a common standard of entrance, so that a man who has qualified to enter on a course of training as a civil, mechanical, or electrical engineer, or as a naval architect, should possess a qualification which will enable him to enter any of these Institutions as a Student member.

From the point of view of the Institution there is a great deal to be said for a very careful selection of Student members, and if there is to be closer co-operation between the different engineering Institutions this question will, I think, have to be faced. I am glad to find that another kind of co-operation is being adopted to an increased extent this year by our own Institution, namely, the reading at joint meetings of papers which are of interest to members of more than one society. This practice has been followed by many of the Local Centres, has greatly increased the general interest in the papers, and has provoked very vigorous discussions.

One of the great evils of the day is unemployment, and it is sometimes suggested that the labours of the electrical engineer increase the number of those who are out of work. There is, however, another side to this question. It is quite true that electrical methods have diminished the amount of manual labour in nearly every industry; on the other hand electrical engineering has created more new industries than any other applied science. There are all over the world hundreds of thousands of people to-day employed in the manufacture of electrical machinery and electrical apparatus; there are also tens of thousands employed in the telegraph and telephone industry, in the business of supplying electrical energy, in the manufacture of electrical appliances, in the making of valves and lamps and cables, in the radio industry, and, within more recent times, in the supplying of equipment for producing talking-films, who would never have found work had it not been for the researches of Faraday and his successors.

The Institution has welcomed these industries and has endeavoured to draw within its scope all those trained engineers engaged in them. With increased efficiency of production, the workers to-day have far more leisure than formerly, and one of the chief tasks of modern education is to enable them to make good use of it. In this respect the electrical engineering industry has given more practical service than any other. Although some people may criticize "wireless" and the "cinema," these undoubtedly provide entertainment and relaxation and give a vast multitude of people a much broader outlook on life than they could otherwise have had. The electrical engineer touches life on every side, and he has surely fulfilled, if anyone has ever done so, the function of an engineer which is laid down in the Charter of the Institution of Civil Engineers, for he has shown the world how to direct "the great sources of power in Nature for the use and convenience of man."

Many of you, no doubt, have read the profoundly interesting Address which Sir Alfred Ewing delivered last month before the British Association, but I should like to quote a few lines of it. "So man finds this, that whilst he is enriched with a multitude of possessions and possibilities beyond his dreams, he is, in a great measure, deprived of one inestimable blessing, the

necessity to toil. He has lost the joy of craftsmanship, the old satisfaction in something accomplished through the conscientious exercise of care and skill, and the world finds itself glutted with competitive commodities produced in a quantity too great to be absorbed."

Something has been lost, but the loss is not uncompensated. Knowledge, though sometimes misapplied, has become more accessible, and we have the possibilities of an increased leisure in which to pursue it. We have the incentive and the opportunity to acquire, through the assimilation of knowledge, right judgment and understanding.

WIRELESS SECTION: CHAIRMAN'S ADDRESS

By L. B. Turner, M.A., Member.

(*Address delivered* 2*nd November*, 1932.)

Table of Contents.

Introduction.

I should like first to express my appreciation of the honour you have done me in electing me Chairman of the Wireless Section. I feel this really is an honour for two reasons. Firstly, since the Section was inaugurated 13 years ago many distinguished men have preceded me in the office which I now hold. Secondly, and more objectively, I am sure that the Wireless Section is a very live and useful department of the Institution. The good attendances at our meetings, and the importance and high standard of many of our papers, testify to this. I hope, and have every reason to expect, that this standard will be maintained during the session now before us.

I propose to devote this Address to the general subject of the thermionic valve. Critics might, perhaps, question whether, nowadays, valves are of suitably special interest to this Section, since their applications are so rapidly spreading to all branches of industry and research. Let us of the Wireless Section remember, however, with a glow of parental pride, that it was in the home of electric signalling—mainly wireless—that the valve was born and bred. In our hands it grew to stature and comeliness; it was we who gave to the world this public servant of boundless versatility, acumen, accuracy, and force.

In Part 1 of the Address I shall set out the divers properties of thermionic tubes, and I shall attempt to use this scheme as the basis of a review of the forms of high-vacuum valves which have been developed for utilizing these properties. In Part 2 I shall dwell at some length on one subject—the obstacles to the amplification of extremely weak signals.

Part 1. THERMIONIC VALVES.

(1) Structural Evolution of Valves.

Table 1 shows the early history of valve invention, and Table 2 the subsequent lines of development of the prominent classes of thermionic valves in use to-day. Notice, as a matter of historical interest,

Table 1.

Hittorf discovers incandescent wire in vacuum acts as cathode (Published early 1884) | Edison effect (Published late 1884)

Fleming diode, 1904

Introduction of third electrode (De Forest, 1907)

Low-vacuum triodes of De Forest, Lieben and Reisz, Round

Valves with gas-freed components and high vacuum, 1913

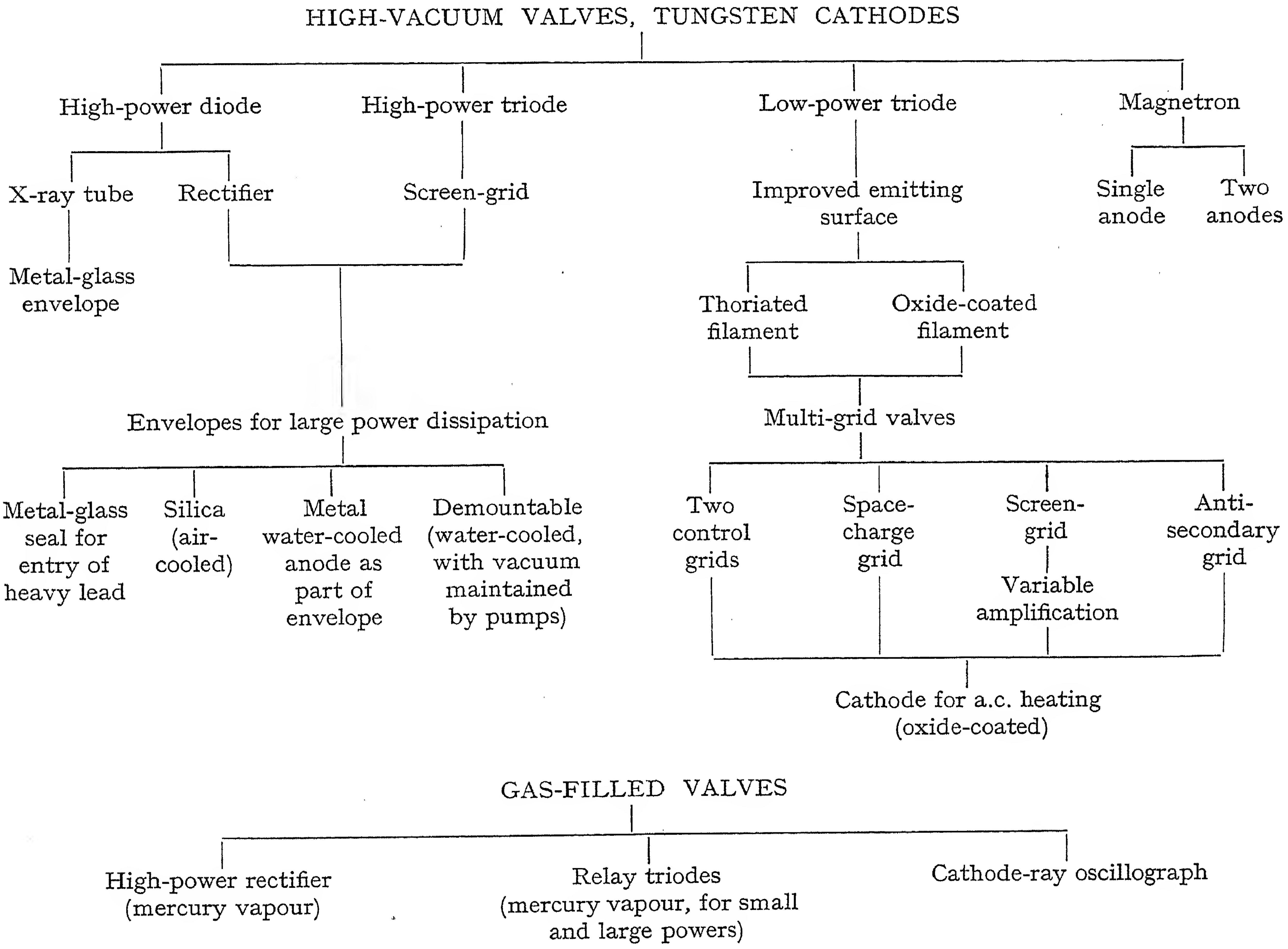
High-vacuum diodes and triodes (American, French, English, German) used during Great War

that I put Hittorf as the first person to publish the phenomenon upon which our whole subject rests, viz. that electricity can pass from matter into surrounding vacuum if the matter is hot enough. Elster and Geitel,* in a summary of their long series of researches with hot-wire electrodes, refer to Hittorf in the following terms: "In this connection we reflect on the facts observed by Hittorf and Goldstein: that, if the cathode glows white-hot, electric currents flow across a vacuum which, at ordinary temperatures of the cathode, behaves as an absolute insulator."

When once the means for producing high-vacuum valves were to hand, the use of soft (i.e. low-vacuum) valves for ordinary signalling purposes soon died out; for any advantageous properties of the valve itself, accruing from ionization of the residual gas, were difficult to control and could be replaced by circuit devices used in conjunction with hard valves. Nevertheless, certain classes of soft valves of great utility have been developed. They are entered at the bottom of Table 2.

It is possible to disentangle many constituent elements in the operating properties of thermionic valves. According to the use of the valve, such and such a property may be essential to the end in view; or it may be incidental and of no significance; or it may be obnoxious and be either avoided or merely tolerated. The valve may be designed for the special end in view; but usually a single valve, according to the way in which it is used, will perform satisfactorily a surprising number of quite distinct operations, depending upon different properties. In the early days of high-vacuum triodes, a single pattern—e.g. the Army "R" triode of the War—was made to serve a variety of purposes. Thus in Fig. 1 this one valve, according to the circuit and the electrode potentials, is shown functioning as follows:—

TABLE 2.



A good collection of the early valves of Table 1—and of some quite modern patterns too—is to be found in the Science Museum at South Kensington. Already at this stage the high-vacuum triode, the instrument of most of the revolution effected by thermionic valves, had been produced. There remained to devise improved technique for obtaining the same ends with the same instrument; to think of new ends to which the same instrument might advantageously be applied; and to improve the instrument. In each of these directions great progress has been made in the last 14 years. Further developments of the instrument are shown in Table 2.

* *Annalen der Physik*, 1889, vol. 37, p. 328.

At (*a*), an anode rectifier, demanding curvature of anode-current characteristic, and preferring no grid current.

At (*b*), a grid rectifier, demanding grid current, and preferring no anode-current curvature.

At (*c*), a heterodyne oscillator (by retro-action), preferring absence of anode-current curvature and of grid current.

At (*d*), a distortionless amplifier, demanding absence of anode-current curvature and of grid current.

At (*e*), a dynatron oscillator (by secondary emission), demanding positive grid potential larger than the anode potential.

more or less intimately acquainted with the complex valve theory and technique which has evolved during the last 20 years, and imagine that—inexperienced though intelligent—we are taking a mental tour of inspection of the development of valve science. Let us make this naïve tour together, trying not to be disconcerted by a frequent return to our real selves and the present day for the purpose of viewing examples of modern apparatus.

(2) Diodes.

If AB in Fig. 2 were a material conductor, it would have the Ohm's-law characteristic P′OQ′ shown in the graph. When AB is a high-vacuum thermionic diode, we find POQS for its characteristic. The curvature at Q gives us a rectifier for the weak alternating potential differences of wireless telegraphic and telephonic signals. The zero current along PO gives us the rectifier for large alternating potential differences; the horizontality at S gives a useful constant-current device; and the same feature, by making it possible to use a very large anode potential e_a for propelling a small controllable stream of electrons i, gives the modern form of X-ray tube.

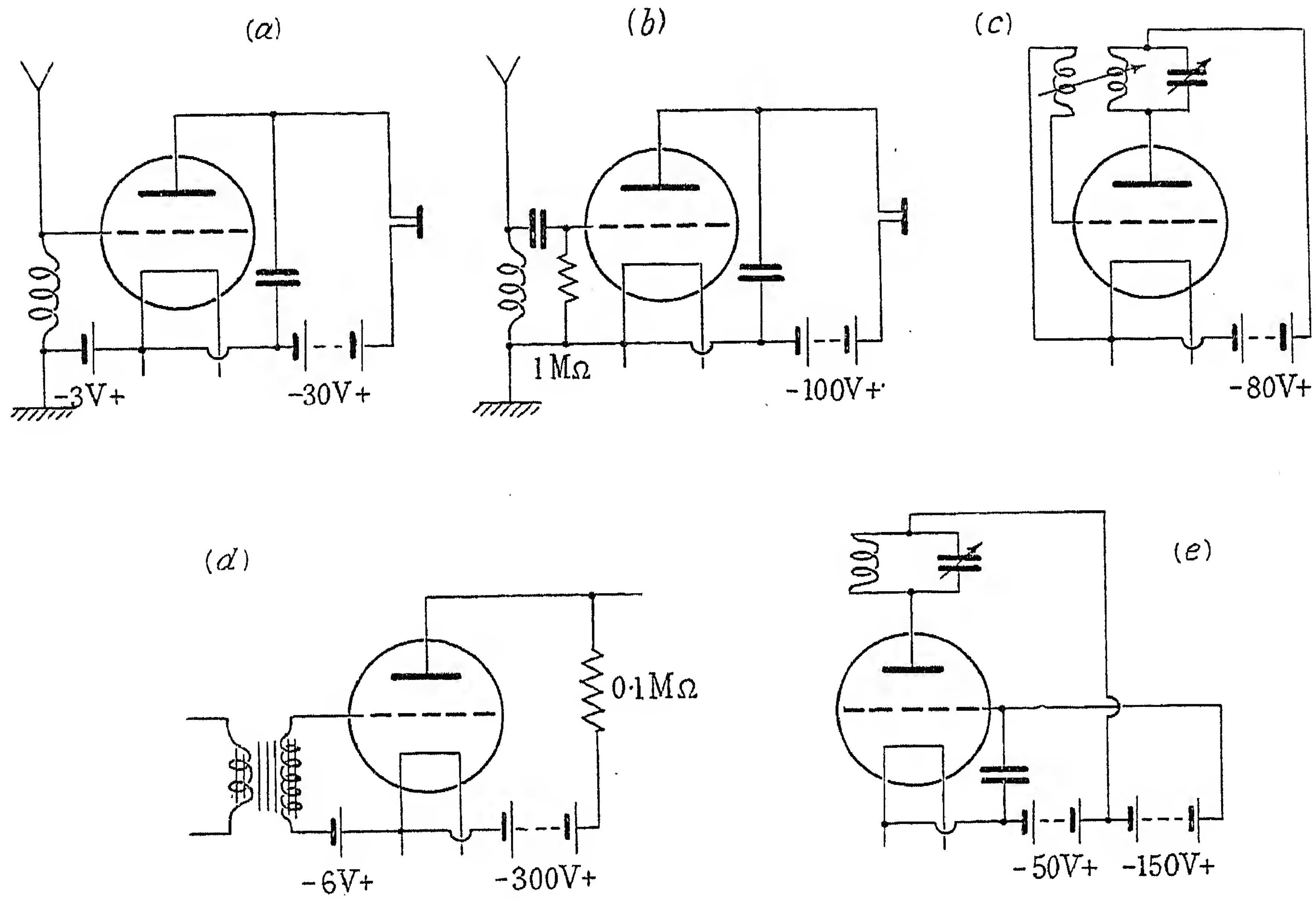


Fig. 1.—Several uses of a single triode.

(*a*) Anode rectifier. (*b*) Grid rectifier. (*c*) Self-oscillator (by retro-action). (*d*) Distortionless amplifier. (*e*) Self-oscillator (by secondary emission).

Let us then distinguish some of these properties of valves upon which their applications depend. We may notice the following:—

(i) Curvature or linearity of anode-current characteristic.

(ii) Curvature of grid-current characteristic, or zero grid current.

(iii) Appreciable or negligible electron emission speeds.

(iv) High or low speed of electrons on reaching anode.

(v) Large or limited total emission.

(vi) Negligible or important effects of secondary emission.

(vii) Ridge-control effect of wires of grid.

(viii) Photo-electric emission from grid.

(ix) Negligible or important time of transit of electrons between cathode and anode.

(x) Diversion of the electrons by a magnetic field.

(xi) Negligible or important ionization of residual gas.

If the valve had been a genus of living animal, Tables 1 and 2 might, I believe, be said to portray the morphological relations of the species. I shall now discuss with like brevity their functional characteristics. Let us forget that we are actually highly sophisticated people,

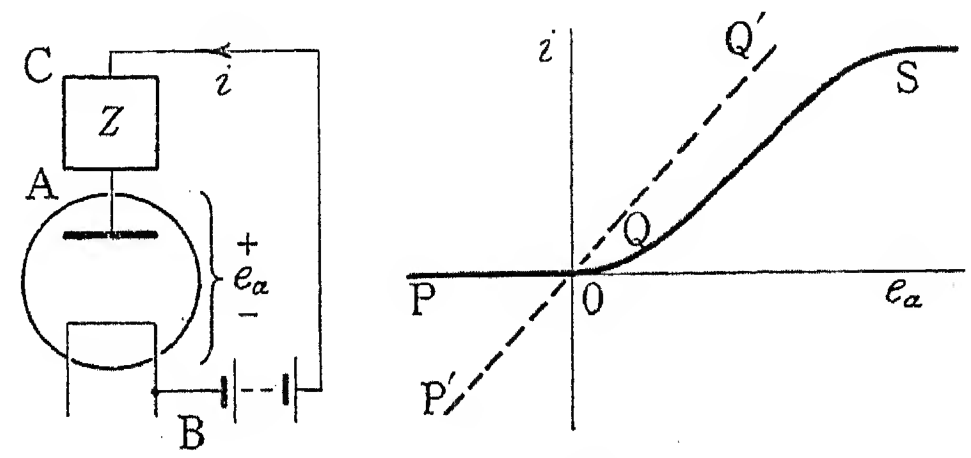


Fig. 2.—Diode.

In Fig. 3, which is a circuit for producing a uniform

time-base in a cathode-ray oscillograph, it is desired to produce across condenser C a potential difference which repeatedly rises uniformly with time and falls back suddenly to the initial value. The diode (actually

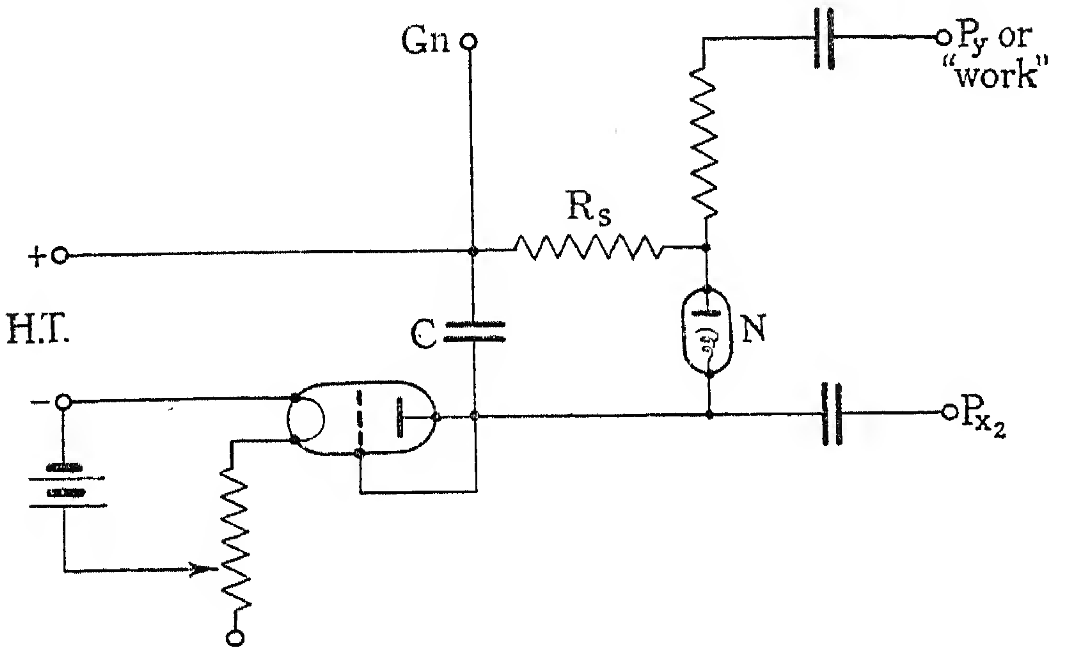
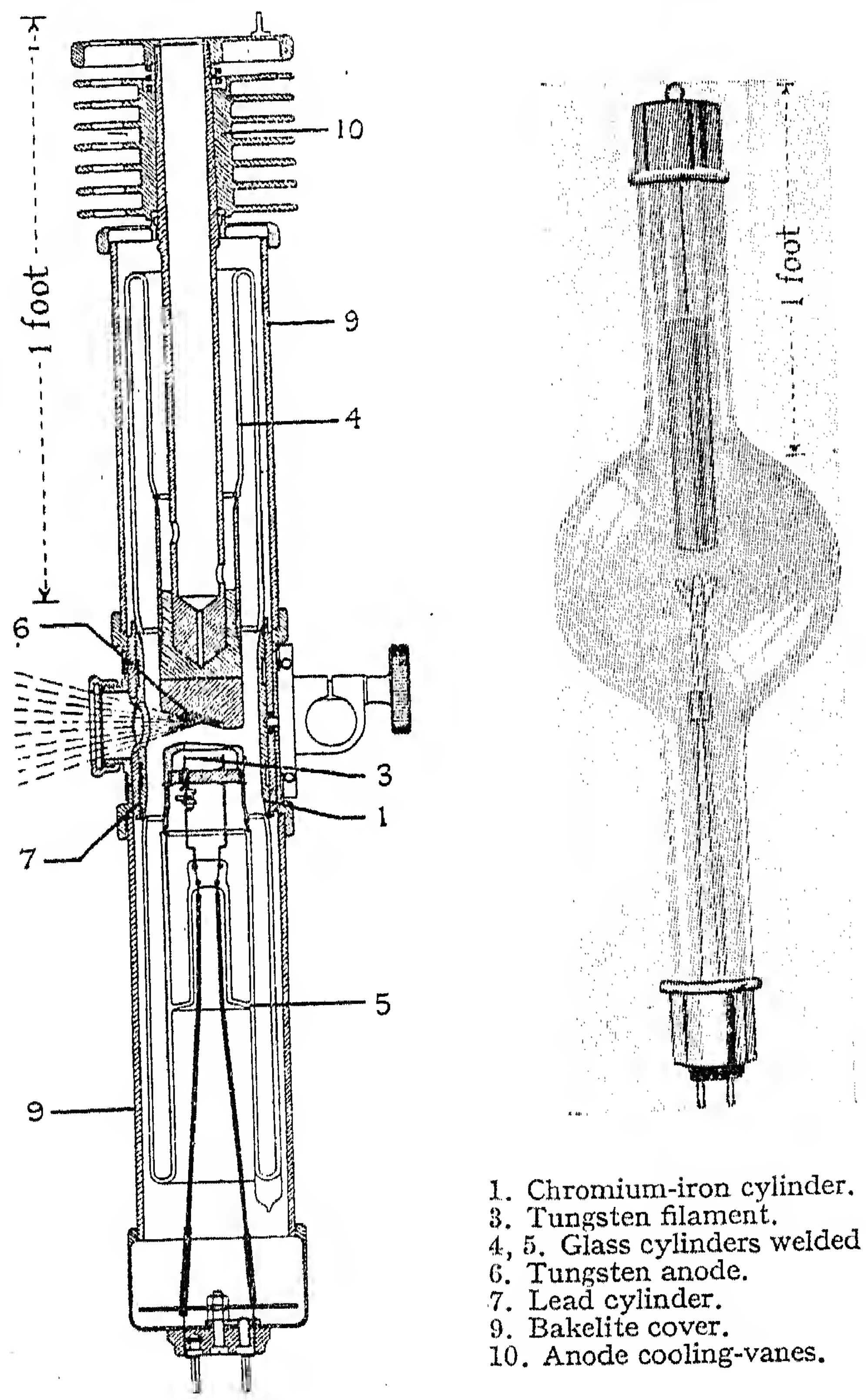


Fig. 3.—Saturated diode for oscillograph time base.

drawn as a triode with grid and anode bunched) has a tungsten filament showing, therefore, well-marked saturation, and allows C to be charged from the high-tension source at a constant current, viz. the saturation



1. Chromium-iron cylinder.
3. Tungsten filament.
4, 5. Glass cylinders welded to 1.
6. Tungsten anode.
7. Lead cylinder.
9. Bakelite cover.
10. Anode cooling-vanes.

Fig. 4.—Contrast in high-tension diodes.

current of the filament. The potential difference of C thus rises at a constant rate, until it is sufficient to strike the neon lamp N; whereupon C rapidly discharges, the lamp goes out, and the potential difference begins to rise anew.

Fig. 4 shows at the right-hand side a high-tension rectifying diode, which might be used for supplying an X-ray tube at 100 kV, or for high-tension cable testing. At the left-hand side is a powerful X-ray tube, capable of taking 10 kW for 1 sec. I have placed both in one illustration as an interesting contrast in the ways of using what are substantially like instruments. Both are high-vacuum, high-tension, thermionic diodes, with tungsten-filament cathodes. In the one, we arrange for the electrons to arrive at the anode with speeds as low as can be contrived (not exceeding, say, 1 kV in the rectifier shown), because their kinetic energy is merely converted to heat at the anode. In the other, the X-ray tube, the electrons are made to arrive with very great velocity (say, 100 kV in this tube); for although, in the X-ray tube also, their kinetic energy is nearly all converted into troublesome heat, the penetration of the X-rays emitted from the anode is nearly proportional to the voltage, and it is penetrating X-rays that we seek.

(3) Triodes.

The shape of the curve anywhere below the saturated region S in Fig. 2 is the effect of the space-charge, that crowd of stagnant unemployed electrons which are the result of the supply from the cathode exceeding the

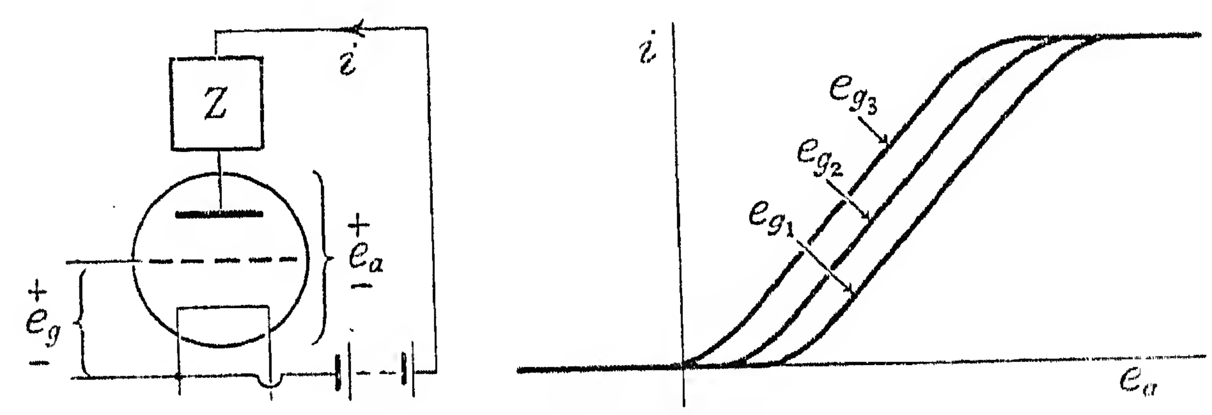


Fig. 5.—Triode.

demand by the anode. The ideas of electrostatics therefore suggest at once that the shape of the i/e_a curve can be modified by bringing other charged bodies into a position where their electrostatic field reaches the space-charge. Such electrodes may be outside or inside the glass envelope, but we soon find that the best control is given by a "grid"—a perforated electrode within the envelope, interposed between cathode and anode, and preferably close to the cathode where the density of space-charge is large. We have reached the 3-electrode tube, the triode, in which the current i is a function of the potentials of two separate electrodes, e_a and e_g (Fig. 5).

(4) Grid Current.

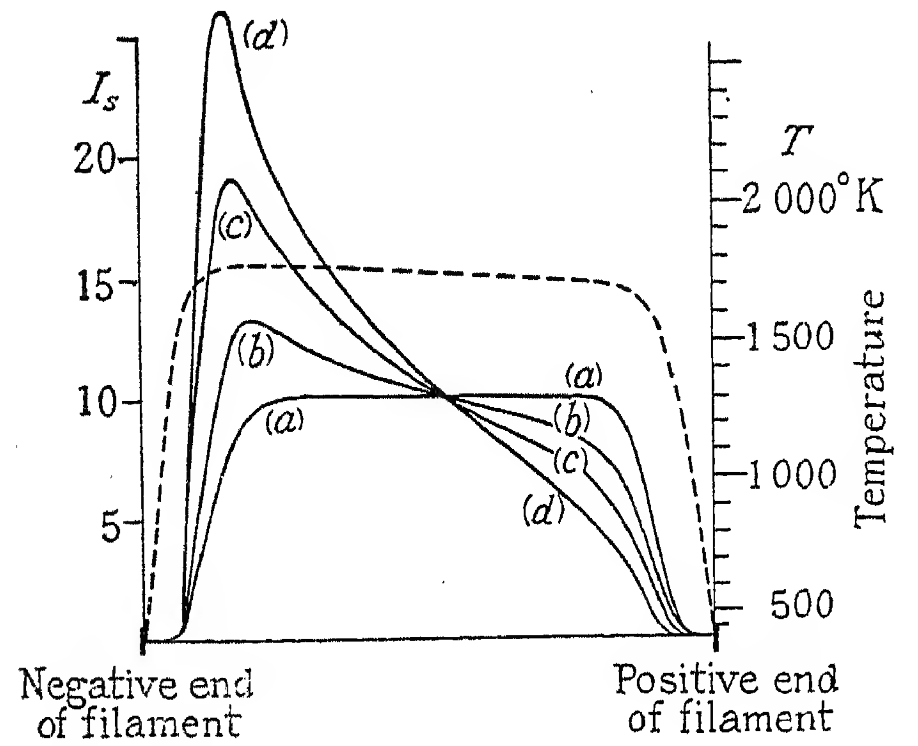
If the control electrode is located inside the envelope, grid current flows when the grid potential is positive, and the grid-cathode characteristic curve resembles the anode-cathode characteristic of a diode. This current-carrying feature of the grid gives us the grid rectifier for the detection of wireless signals, and the means of providing automatic grid-bias in valve oscillators and power amplifiers.

Despite the immersion of the grid within the electron stream, when its potential is below that of the cathode no current flows in the grid connection. This feature of the triode gives scope for the vast range of applications wherein the power in some output circuit Z (in

Fig. 5) is controlled by an input signal δe_g from which negligible power is demanded. Of all valve applications, these, I think, are the most valuable.

(5) Improvements in Receiving Triodes.

The substitution, for the pure-tungsten-filament cathode heated to temperatures in the neighbourhood of



(a) $\frac{I_s}{I_h} = 0$ per cent. (b) $\frac{I_s}{I_h} = 5$ per cent.

(c) $\frac{I_s}{I_h} = 10$ per cent. (d) $\frac{I_s}{I_h} = 20$ per cent.

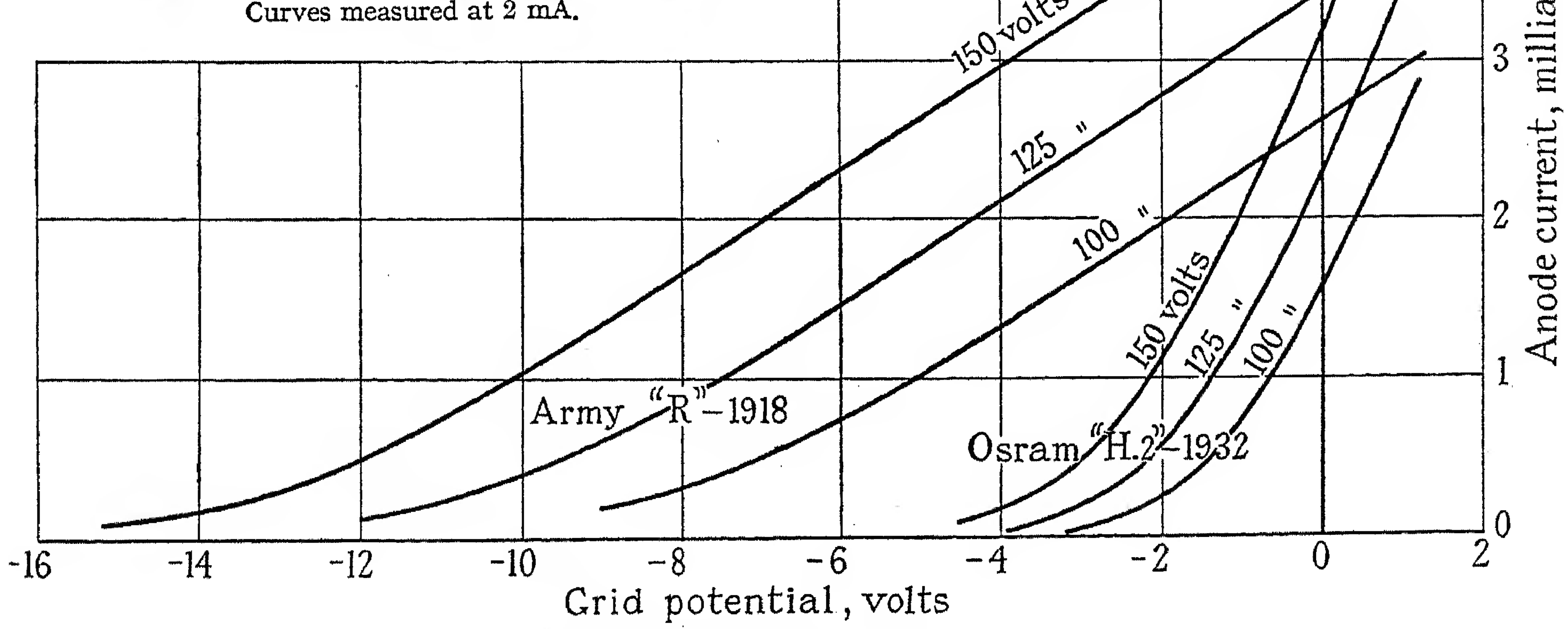
The dotted curve shows the value of T for curve (a).

Fig. 6.—Approximate distribution of the emission along a thoriated tungsten filament heated by direct current.

2 400° K.,* of the modern oxide-coated cathode running at temperatures as low as 800° K., has profoundly affected both the design of receiving valves and their performance. The great economy in heating power—from, say, 0·5 to 0·01 watt per milliampere of emission—is by no means the chief consideration, whether for the designer or for the user of the valve. Quite apart from the various delicate, and still largely empirical, processes for obtaining the highly emitting film on the surface of the modern cathode, various new considerations are introduced by the lowered temperature of the filament and the reduced current in it. I will mention three, of which the first and second are adverse, and the third favourable, to the production of highly effective receiving valves.

(i) Heat is radiated from a hot body at a rate proportional to nearly the 5th power of the temperature; hence a tungsten filament loses most of its heat by radiation to the surrounding electrodes. If the anode rises to a dark red temperature, it radiates to the filament a power equal to about 3 per cent of the filament heating power. On the other hand, a coated filament, running at a temperature of 1 000° K., receives this same percentage of its much smaller heating power, by radiation from the grid and anode surrounding it, when their temperature is only about 160° C. The temperature of the filament is therefore much affected by the temperature of the grid and anode.

(ii) Whatever the external connection between anode and filament may be, the current leaving the negative end of the filament must exceed the current entering the positive end by an amount equal to the space current in the valve. Consequently the filament is hotter towards the one end than towards the other; and unless the space current is small compared with the heating current, the emission is very unequally distributed along the filament. This effect in a valve with a thoriated filament is shown in Fig. 6. H. Barkhausen, from whose book this figure is taken,* concludes that the space current I_s should not be allowed to exceed 10 per cent of the filament heating current I_h—a very practical limitation when filament currents of 0·1 ampere, and even less, are used.



Valve	Filament			Amplification factor μ	Anode resistance ρ	μ^2/ρ
	V	A	W		ohms	A/V
"R"	4	0·65	2·6	10	30 000	0·0033
"H2"	2	0·1	0·2	34	33 000	0·035

Curves measured at 2 mA.

Fig. 7.—Comparison between old and new receiving triodes.

(iii) The reduction of filament distortion caused by change of temperature has permitted the adoption of much smaller clearances between the grid and filament than were feasible with tungsten filaments. To this change, coupled with ample emission, the superior performance of the modern valve is mainly due.

* T° K. means T Centigrade degrees above absolute zero.

* "Elektronenröhren," 1931, 4th ed., vol. 1, p. 29.

Fig. 7 shows an interesting contrast between the old and the new, and speaks for itself. I have tabulated μ^2/ρ because this, I think, measures, as well as any single quantity can, the practical gain obtainable from an amplifying valve in terms of power or square of voltage. Despite a filament power divided by 13, in its operation the new valve may be said to be 10 decibels better than the old.

With the indirectly heated cathodes we have further advance, and the return to a large heating power—4 watts—is of no consequence to the user who draws his power from the mains. (I am told, by the way, that still in this country out of every three receiving valves sold only one is of the indirectly heated type; but that, on the other hand, while the sale of receiving valves is still increasing, the sale of the directly heated type appears to have reached its maximum.) The large heating power of the indirectly heated type is, nevertheless, of some consequence to the designer of the valve, because it warms the grid and anode. For the anode it is relatively simple to provide adequate cooling surface, but this is not so easy for the grid. A novel and ingenious construction of the electrodes, to facilitate cooling of the grid, is shown in Fig. 8. Here the grid is very effectively cooled by conduction of heat to the large exposed cooling vane, to which every spire of its winding is welded in two places. In these valves it has been found feasible to reduce the clearances to extremely small values, viz. about 0·3 mm between cathode and grid, and 0·4 mm between grid and anode. Despite this close spacing, the grid temperature does not rise above 300° C., and because of the close spacing the conductances of these valves are exceptionally high. One pattern, called a detector or amplifying valve, has a grid wound with about 45 turns per cm. At 8 mA it shows an amplification factor of 102, the anode resistance being only 12 500 ohms.

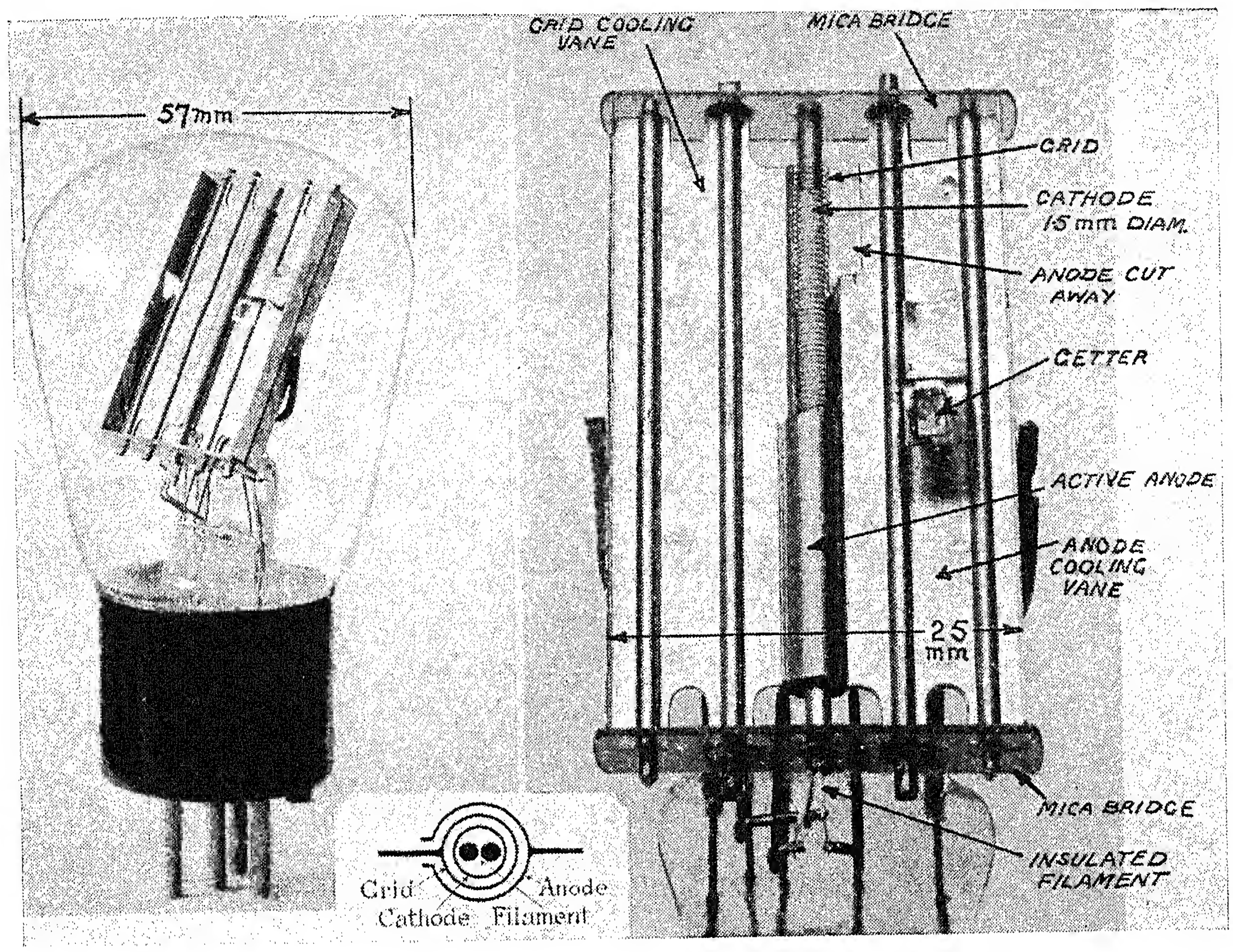


FIG. 8.—" Micromesh " valve, and enlarged view of electrodes with anode partly cut away.

(6) ELECTROMETER VALVES.

In all amplifiers it is desired to keep the grid input current negligible; but what is negligibly small in, say, amplifiers for electric signalling may be enormous in amplifiers for other applications—notably the measurement of hydrogen-ion concentration with a glass electrode, and the measurement of light with the photo-electric cell. Amplifier valves characterized by the extreme smallness of grid current under working conditions are called " electrometer valves."

In Fig. 9, if the grid-leak resistance R is made sufficiently high—it may be of the order of a million megohms—the minimum illumination producing any specified change of grid potential at the triode is determined by the minimum value of grid current which can be maintained steady in the absence of illumination.

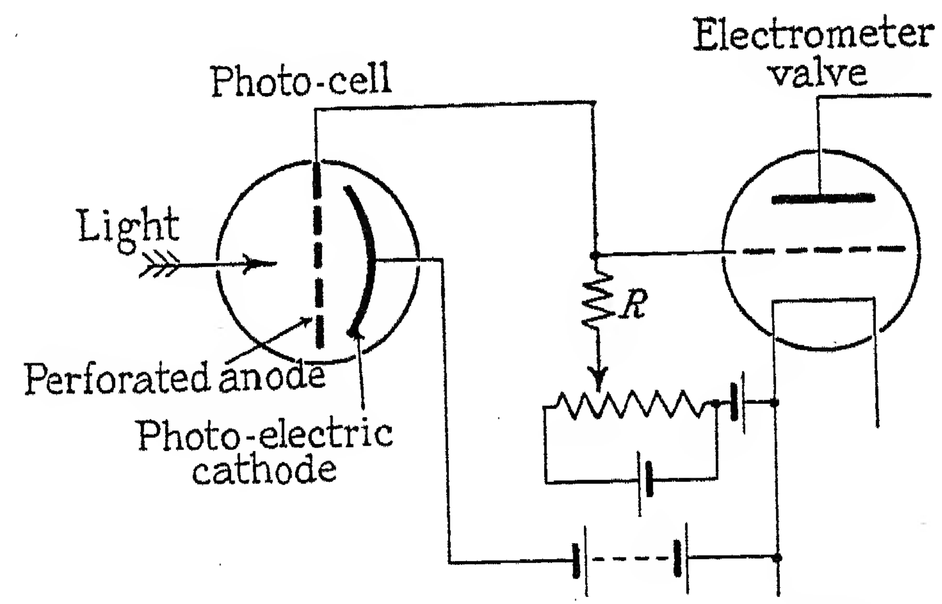


FIG. 9.—Electrometer valve actuated by photo-cell.

Causes of grid current, positive and negative, which are negligible in other applications of the valve, here assume controlling importance. These are:—

(i) Surface leakage at the grid seal and the grid support within the envelope.

(ii) Ionization of residual gas.

(iii) Emission of positive ions from the cathode. (This might be 10^{-11} ampere from a well-aged tungsten filament at 2 100° K.)

(iv) Photo-electric emission from the grid, excited by the light incident from outside the envelope and from the filament. (With a bright tungsten filament, the latter would be of the order 10^{-12} ampere, and with a thoriated filament at 1 700° K. it would be some 10^{-15} ampere if the grid had become thorium-coated.)

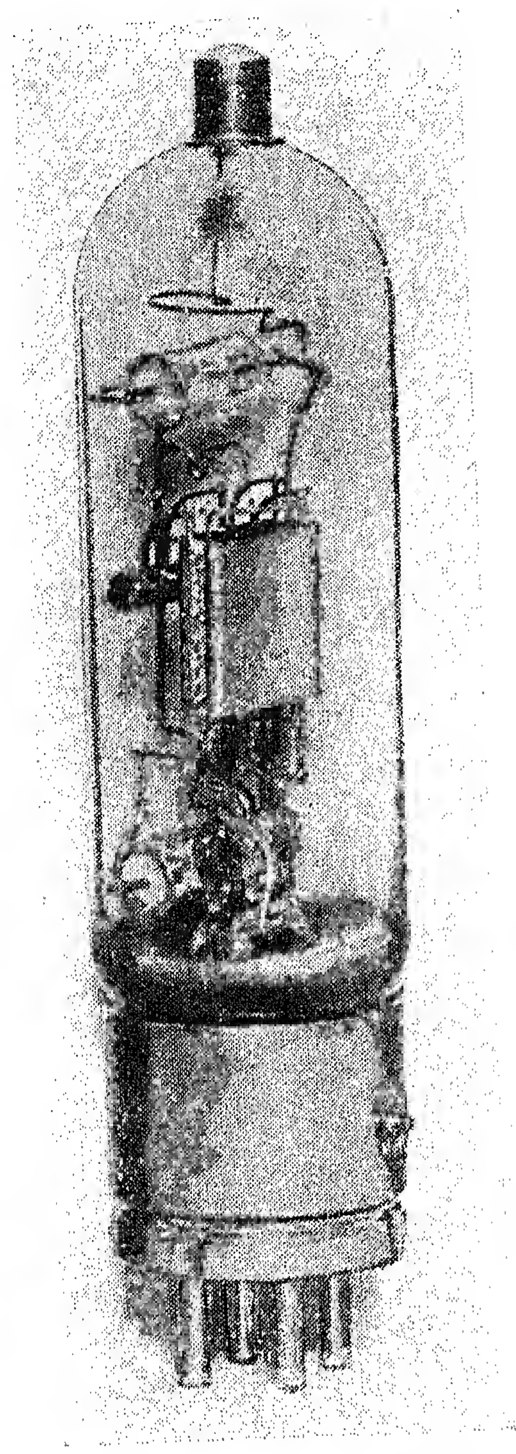


Fig. 10.—American electrometer valve (tetrode).

Leakage (i) is reduced by taking care of the quality of the glass (or quartz) insulating supports, and even by shrouding the grid connection in a sleeve of vacuum protecting it from atmospheric ionization. Ionization of residual gas (ii) is avoided by using an anode potential (e.g. 5 to 10 volts) lower than the critical ionizing value. Current from emitted positive ions (iii) is reduced as far as possible by the use of a selected, dull, thoriated or oxide-coated filament; and, in the electrometer valve shown in Fig. 10,* by inserting a space-charge grid at a potential of $+ 3$ volts between the filament and the control grid. Photo-electric emission (iv) is reduced by using a dull filament, and by screening the valve from external illumination. Fig. 11 shows another electrometer valve and its operating conditions.

* I am indebted to Dr. A. W. Hull for this photograph.

Using the electrometer valve of Fig. 10 and applying all such precautions, it is possible, as the extreme practical limit at present, to reduce the grid current to about 10^{-18} ampere.* This current is, however, the out-of-balance of two nearly equal and opposite currents of about 10^{-15} ampere, one due to photo-electric emission from the grid, and the other—controlled by the potential divider determining grid bias—to electrons emitted by the filament with speeds enabling them to reach the grid. The shot and flicker effects, discussed in Part 2 of this Address, have therefore to be calculated for a current of 2×10^{-15} ampere.

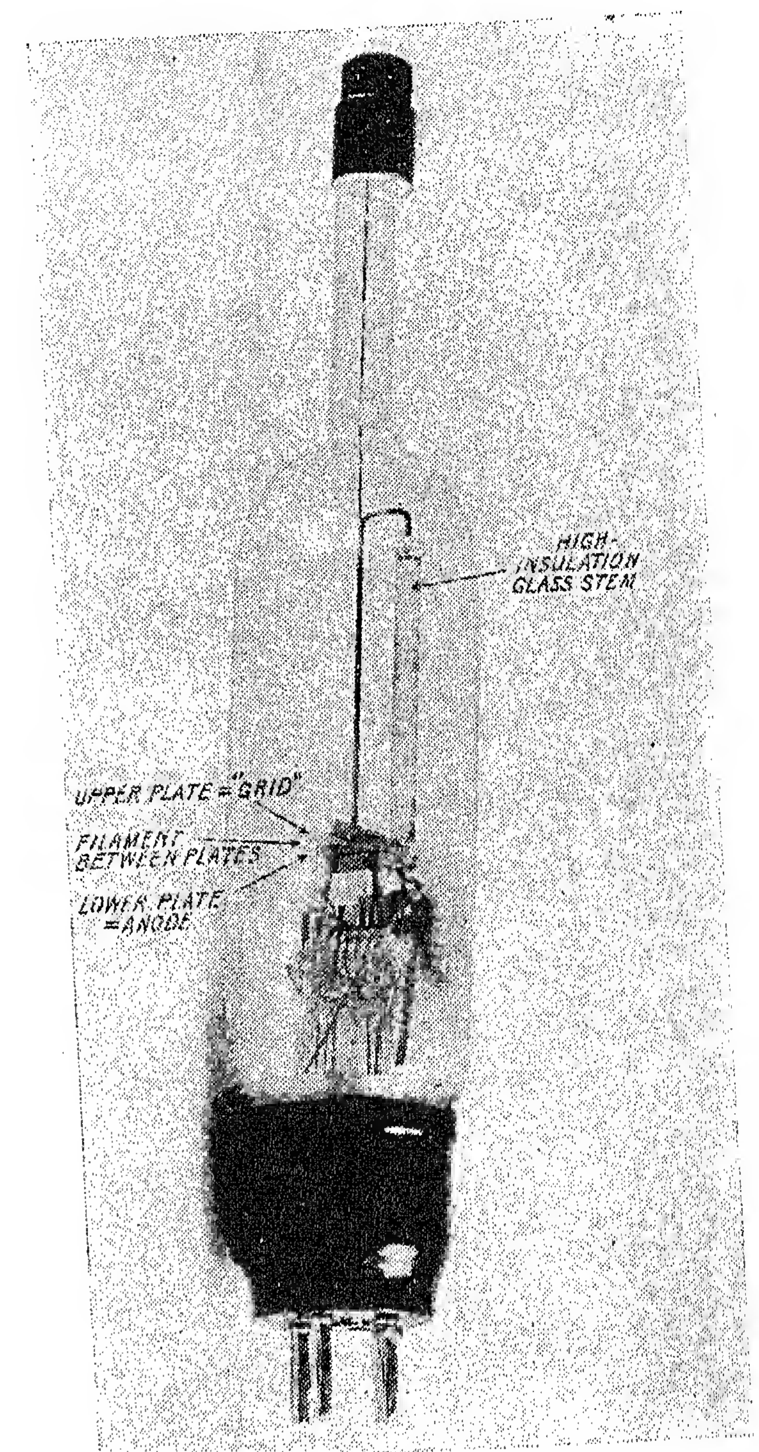


Fig. 11.—British electrometer valve (triode).
Filament: 1·0 V; 0.1 A. Anode: 4–6 V. Grid: − 2 V.
Transconductance = 0·04 to 0·06 mA/V.
Grid to other electrodes: insulation resistance = 10^{15} ohms, capacitance = 1·5 $\mu\mu$F.

(7) Triode Oscillator.

Reverting again to our tour, we have got our amplifying triode giving at the anode a magnified copy of what is applied at the grid, and without appreciable consumption of power by the grid. It is obvious that we can use it to maintain a system in self-oscillation. An *LC* combination comprised in the anode circuit is the seat of a steady alternating current if the grid is excited by a steady alternating potential difference; and this grid excitation can be provided spontaneously by the simple expedient of some appropriate back-coupling from the anode. We have thus arrived at means of introducing negative damping into any oscillatory system, so that decrements, which nature usually prefers shall be positive, can be held as near to zero as

* A. W. Hull: "Electronic Devices as Aids to Research," *Physics*, 1932, vol. 2, p. 409.

man may choose, and even as a transient condition be reversed in sign.

The triode thus becomes the facile instrument for maintaining oscillations of many kinds. It is chiefly so used for providing weak and strong alternating currents of radio-frequencies up to, say, 100 million cycles per sec. It is also much used for producing

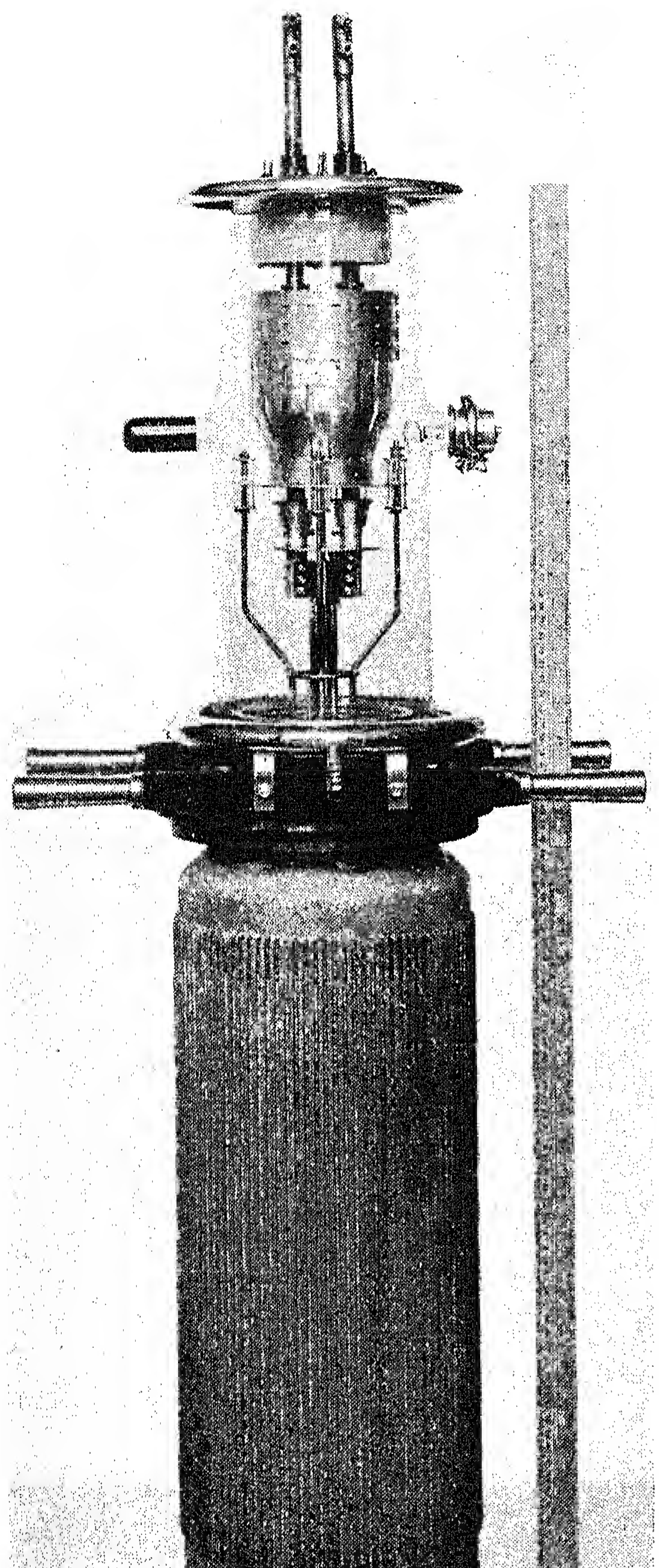


FIG. 12.—500-kW sealed-off water-cooled valve.
The wooden scale is 100 cm long.

currents of acoustic frequencies, and even for maintaining mechanical oscillation by resort to electromagnetic or piezo-electric connection between the mechanical and electrical systems. The combination of a triode, *qua* escapement, with a quartz crystal, *qua* pendulum, provides a timekeeper vying for precision with the best astronomical clock; it *is* a clock, beating a million times a second.

The development of triodes as oscillators has been mainly towards higher powers and higher frequencies. The first transatlantic telephony was accomplished, in 1915, with a valve oscillator comprising some hundreds of the small triodes then available, connected together. It is normal practice to-day—or at any rate will be to-morrow—to use transmitting valves to which the anode supply is of the order of 100 kW per valve, e.g. at the Warsaw broadcasting station. Illustrations of what are, I believe, the largest valves yet constructed, each for an input of 500 kW, are shown in Figs. 12, 13, and 14. Fig. 12 shows a metal-glass, water-cooled, sealed-off valve; Figs. 13 and 14 show parts of a demountable valve. The latter may be taken to pieces with a spanner, and is used with its pumps in continuous operation. This valve was referred to in Col. Angwin's Address* to this Section a year ago. It was run experimentally with an input of over 500 kW at the Rugby station, but has since undergone alterations. Fig. 13 shows the anode, formerly of steel but now of copper. Fig. 14

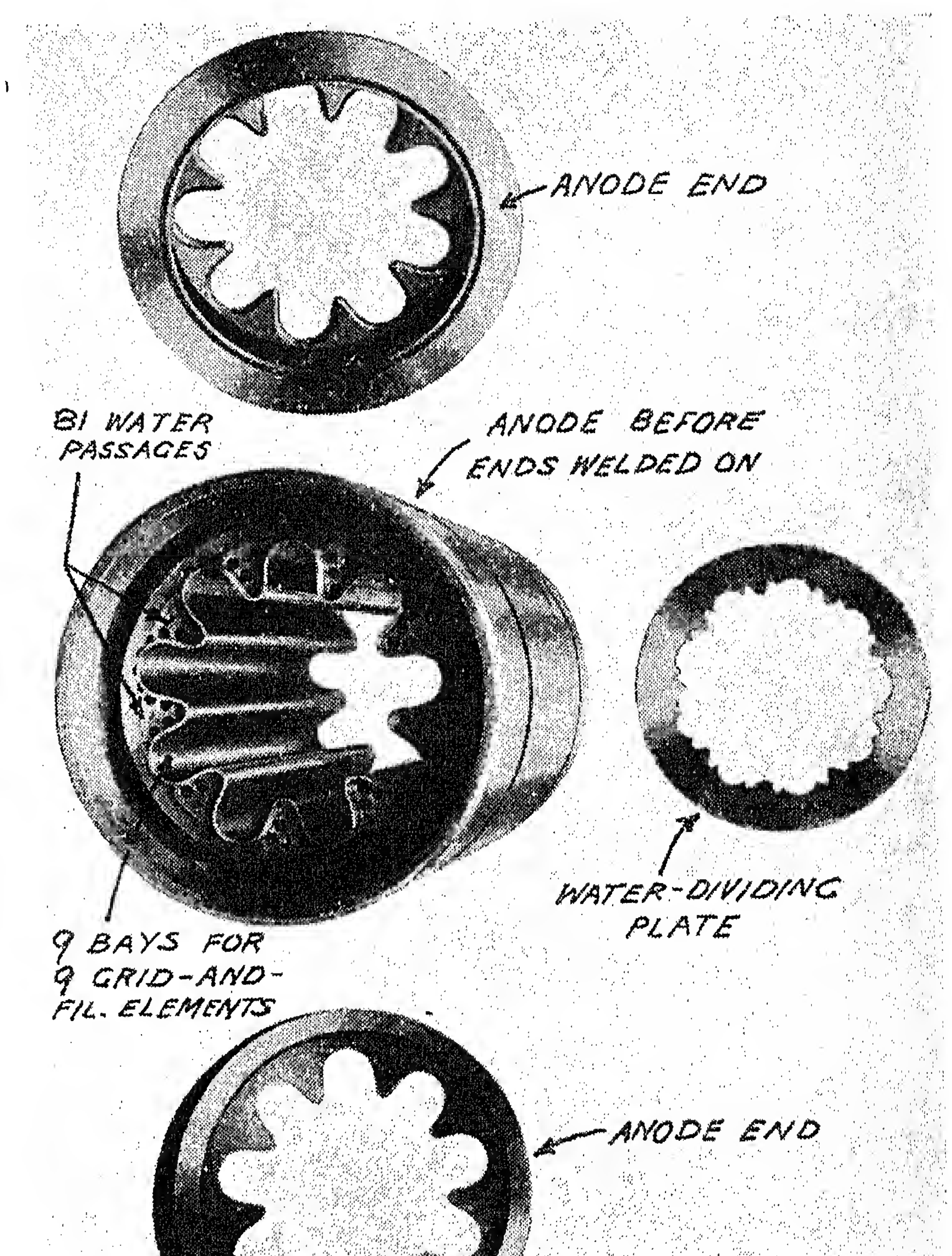


FIG. 13.—500-kW demountable valve: anode before the ends are welded on.

shows the filament-supporting structure, with one of the 9 filaments in position, and also (to a rather larger scale indicated by the receiving valve included in the photograph) the grid-supporting structure, with 7 of the 9 U-section grids in position.

A smaller valve of the same general type has also been produced. It has a cylindrical anode, of bore $1\frac{1}{2}$ in. and active length $4\frac{1}{2}$ in. On medium wavelengths (e.g. 600 m) it will run self-oscillating with 30 kW

* *Journal I.E.E.*, 1931, vol. 70, p. 17.

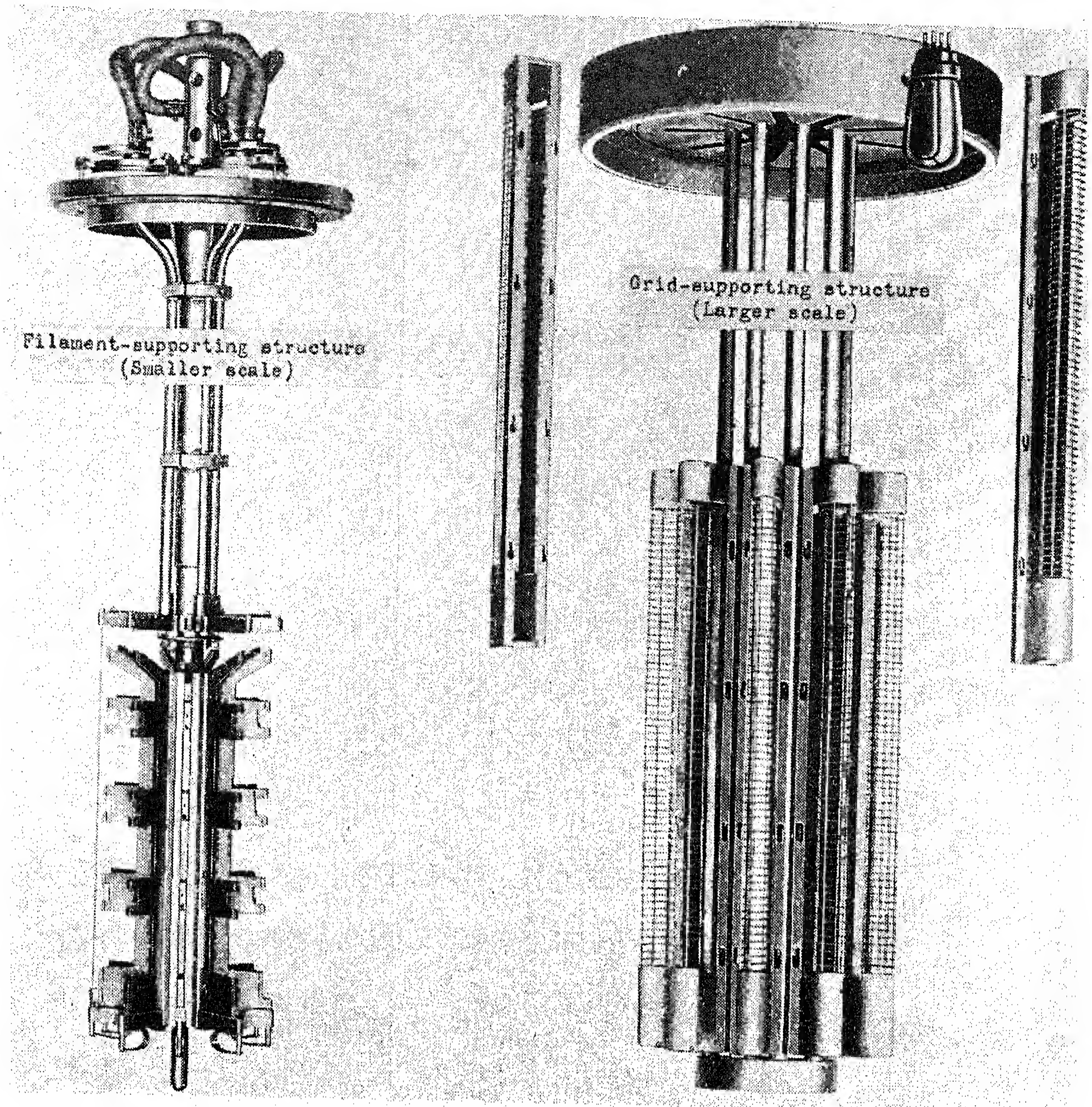


FIG. 14.—500-kW demountable valve: filament and grid structures.

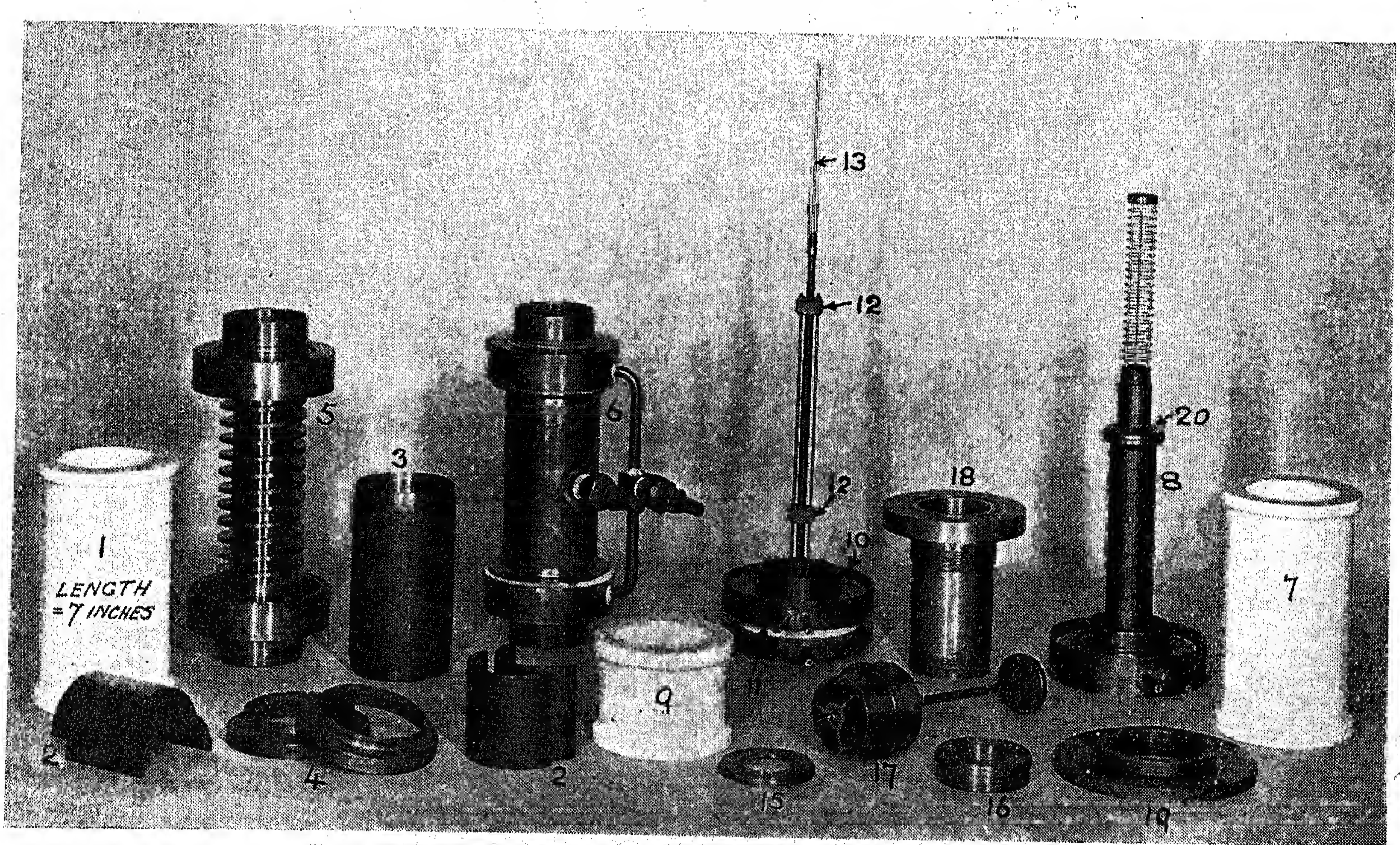


FIG. 15.—Component parts of 40-kW demountable valve.

1. Anode-pump pot.
2. Liners which go inside anode jacket (to fill dead space).
3. Anode jacket.
4. Expansion rings for anode jacket.
5. Anode body with end flanges in position.
6. Completed anode.
7. Anode-grid pot.
8. Grid flange, support tube, and grid. (Grid removable at joint 20.)
9. Grid-filament pot.
10. Filament flanges, separated by 11.
11. Filament-filament pot.
12. Steatite insulators supporting 13.
13. Filament tensioning rod.
15. Filament-pot guard-ring.
16. Grid-pot guard-ring.
17. Pump guard electrode which sits inside 1, resting on 18.
18. Pump flange.
19. Flange holding 18 and supporting pump.

input per valve, and with the porcelain cylinders replaced by silica one of these valves has run with 20 kW self-oscillating at the extremely short wavelength of 4·9 m. Two such valves have been run for several months by the Post Office as the final stage in the transatlantic telephone transmitter GBS, of which the normal power input is $4\frac{1}{2}$ A at 9 kV, and the wavelengths 16 to 43 m. Fig. 15 shows a set of component parts of these valves.

(8) Internal Anode-Grid Capacitance.

A study of the static characteristics of a triode, and their bearing on the behaviour of circuits connected to

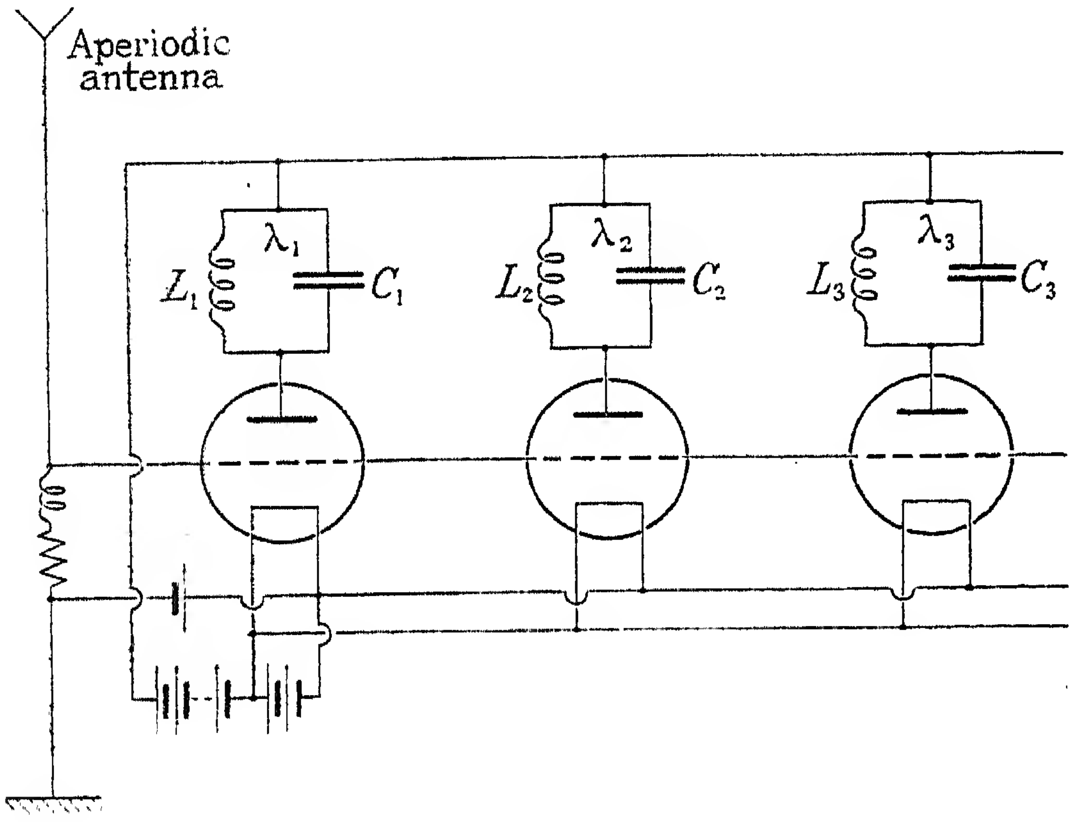


Fig. 16.—Triodes used as separators.

it, suggests immediately that one of the virtues of this remarkable instrument is the removal of reactive relations between the input and output systems. Newton's law, "action and reaction are equal and opposite," can be applied to a cricket bat and the ball it is hitting, or to the primary circuit of a transformer

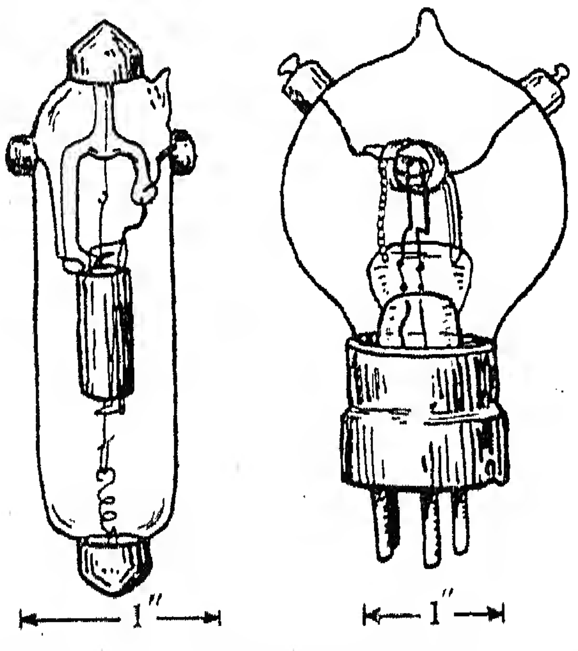


Fig. 17.—Triodes with small inter-electrode capacitances.

and the secondary circuit it is influencing, but not to the grid and anode circuits of a triode. The grid potential of a triode amplifier, by controlling the stream of electrons entering the anode, does affect the anode potential; but if no electrons are entering the grid, the anode potential cannot in like manner affect the grid potential. Valves are sometimes used solely for the sake of this peculiar non-reacting property, the amplification being merely incidental or even less than unity. Thus it has been proposed* to make use of this property (Fig. 16) with the object of letting a single antenna actuate any number of tuned instruments receiving simultaneously

* British Patent No. 189693—1922.

separate transmissions, in such a way that the tuning adjustments of the several instruments are entirely independent.

Back-action from anode to grid is completely absent, however, only if there is no coupling between the grid and anode circuits, and in real triodes some coupling is provided by the unavoidable small internal capacitance between these electrodes.

The inconvenient effects of this anode-grid capacitance have been known from early times. They are ordinarily inappreciable at acoustic frequencies, but they become progressively more pronounced as the frequency rises, until at the modern short-wave wireless frequencies they assume a prime importance. Thus a grid-anode capaci-

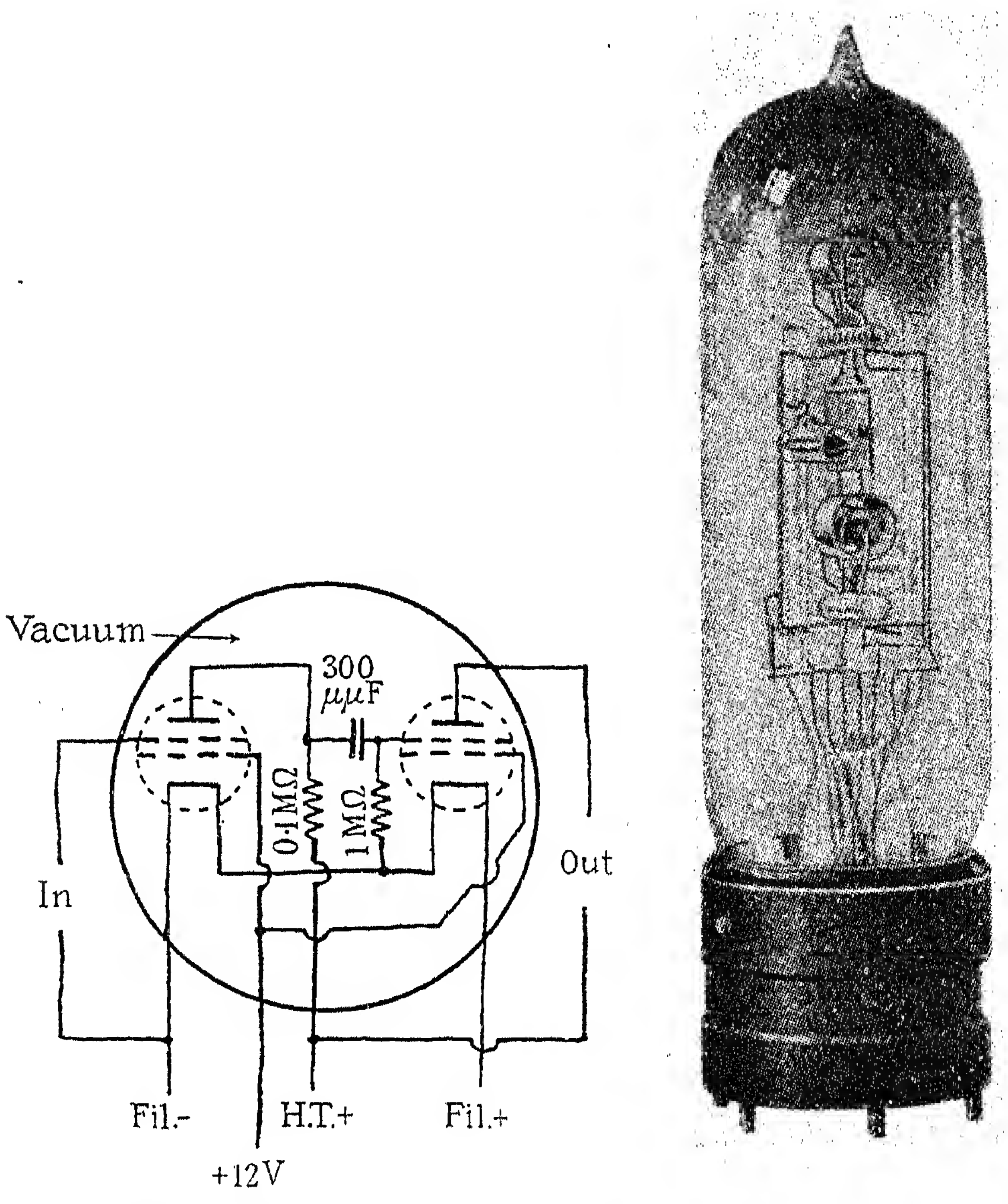


Fig. 18.—Two-valve amplifier in a single bulb.

tance of 5 $\mu\mu$F has a reactance of about 100 MΩ at 300 cycles per sec., falling to about 1 000 Ω at a wavelength of 10 m. When high-frequency amplifiers were first produced, attempts to reduce the stray capacitance between grid and anode were made by leading out the connections at well-separated spots on the bulb, despite the consequent serious increase of manufacturing cost. Examples of such receiving triodes are the early French "horned" and the Marconi "V 24" patterns (Fig. 17). In the latter, the capacitance between the anode and the bunched grid and filament is about 1·8 $\mu\mu$F.

In the effort to obtain high-frequency amplifiers with the minimum possible stray capacitance, amplifiers have actually been constructed* with several triodes (or equivalent tetrodes) and their associated resistors and condensers, all inside a single vacuous bulb. Fig. 18 shows one of these.

In modern transmitting triodes also, the leads to anode and grid are usually well separated, and this is

* *Jahrbuch der drahtlosen Telegraphie*, 1926, vol. 27, p. 19.

very necessary if they are to be used for short waves. Fig. 19 shows a double-ended water-cooled triode suitable for wavelengths down to 15 m. (Anode potential and dissipation up to 12 kV and 15 kW repectively; overall length 74 cm.) At such high frequencies the capacitance currents between anode and grid are very large, and the grid seal must be capable of passing without overheating a current which may be many times the total emission of the cathode. The fused joint, nowadays so easily made between glass and a thin edge of copper, is used not only between the central tubular copper anode and the glass ends of the envelope, but also for

FIG. 19.—Water-cooled triode for short waves.

the filament and grid seals. The thin-edged copper thimbles, with stout axial rod conductors, are seen at both ends of Fig. 19, and the same form of seal is seen more clearly in Fig. 20.

In a recent paper describing experiments devoted to the production of oscillations of the order of 1 m wavelength by the use of retro-acted triodes, L. Rohde* remarks that to-day it is more difficult to obtain 10 watts output at 1 m wavelength than 10 kW at 6 m. He gives the data reproduced in Table 3. The columns headed AG, GK, AK, give the anode-grid, grid-cathode, and anode-cathode capacitances respectively of many patterns of triodes. The working capacitance between anode and grid is

$$C_{AG} + \frac{C_{GK} \cdot C_{AK}}{C_{GK} + C_{AK}}$$

* "Transmitting Valves for the Production of 1-metre Waves," *Hochfrequenztechnik und Elektroakustik*, 1932, vol. 40, p. 4.

It will be seen that, in all triodes for anode dissipations of 100 watts and above, the effective anode-grid capacitance is upwards of 5 $\mu\mu$F.

According to circuit conditions, the effect of anode-grid capacitance may be either to introduce additional damping, or to do the opposite and tend to produce self-oscillation. The former effect in triode detectors —sometimes called the Miller effect—is now well known. The opposite effect is most in evidence in wireless

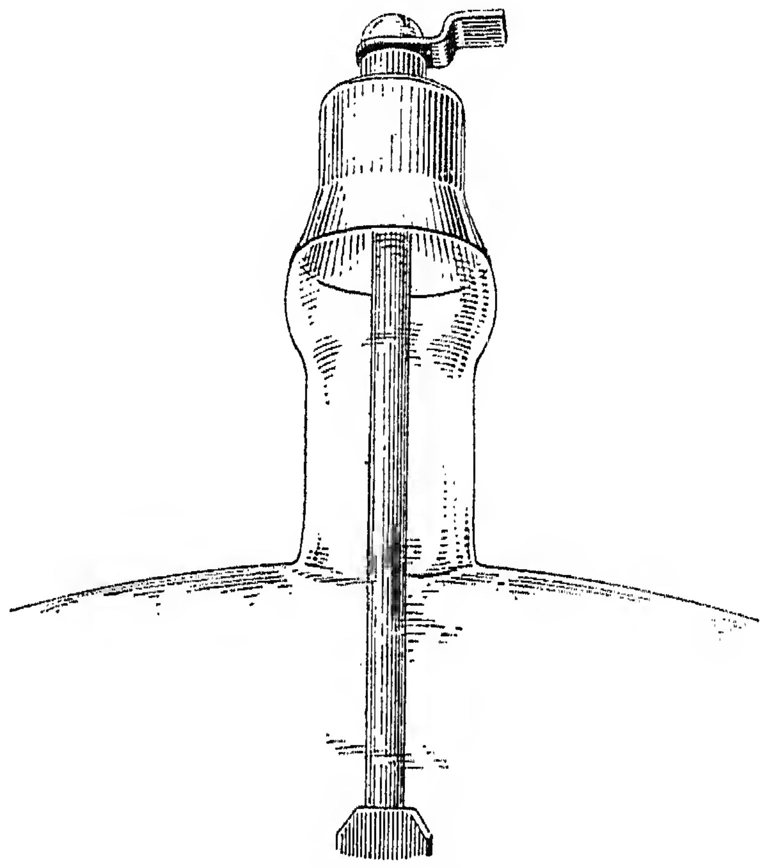


FIG. 20.—Copper-thimble seal for large current.

telegraph or telephone transmitters where, as is now customary, modulation is effected at a low power level, with subsequent large high-frequency amplification. The shorter the wavelength the greater are the difficulties introduced by this capacitance.

Of the two methods of countering this defect of the triode, the older "neutrodyne" circuit device of L. A. Hazeltine* balances out the effect of the undesired capacitance, whereas the newer screen-grid device

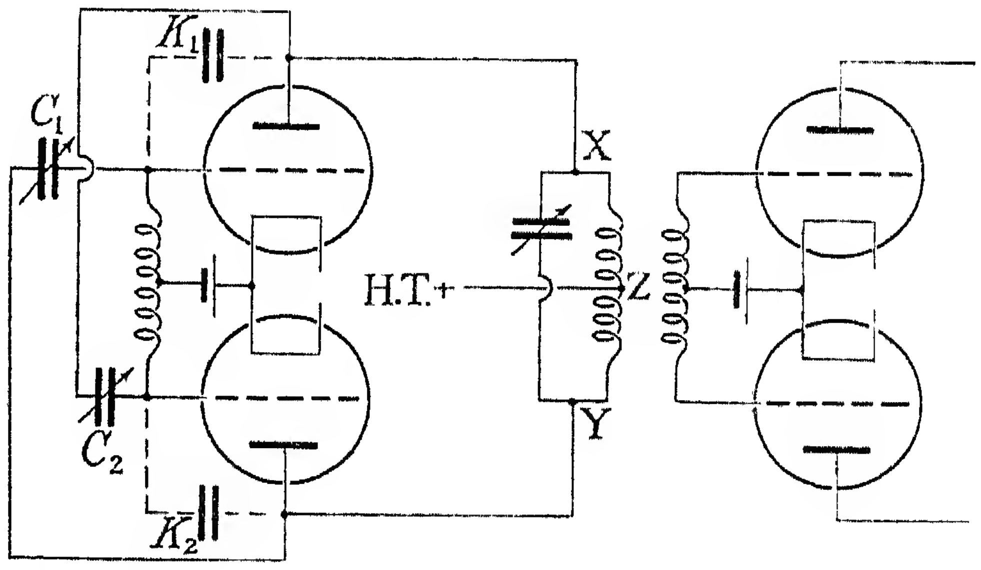


FIG. 21.—Neutrodyned push-pull disposition.

removes the capacitance. The neutrodyne method is highly efficacious, as regards the normal frequency of the circuits, especially in symmetrical anti-parallel (or "push-pull") dispositions, as in Fig. 21. Here K_1, K_2, represent the anode-grid capacitances, and C_1, C_2, the balancing condensers. If $e_X = - e_Y$, reaction from anode to grid is removed by making $C_1 = K_1$, and $C_2 = K_2$. The distribution of inductance and capacitance in the external circuits, however, leaves it always qualitatively possible for self-oscillations of a frequency

* J. F. DREYER and R. H. MANSON: "The Shielded Neutrodyne Receiver," *Proceedings of the Institute of Radio Engineers*, 1926, vol. 14, p. 217.

higher than the normal to occur, and these can be very troublesome.

Improved stability of neutrodyne balance is likely to be obtained if it is effected within the valve itself. This is accomplished in the design of E. J. C. Dixon, in which one envelope contains, in effect, the two valves of a push-pull combination together with the balancing condensers. An extension of grid 1 is arranged in proximity to anode 2, and an extension of grid 2 in proximity to anode 1. The grid extensions are, of course, placed where they have no influence on the electron currents. Valves of this type have been constructed in glass for 250 watts, and in silica for 2 kW. This self-neutrodyne principle seems to necessitate a flat-plate construction, a form making it difficult to establish rigid electrode spacing which shall remain unchanged after the severe heat treatment of the pumping process. Fig. 22, which gives a set of static characteristics for one of the silica heptodes, shows that although the symmetry as regards electron currents is not perfect, it is fairly good.

An interesting point about this design is that it seems to be the only way in which at very high frequencies the anode and grid leads entering the valve can be kept free from heavy capacitance currents.

TABLE 3.

Type	Rated anode dissipation	Wave-length of shortest self-oscillation	Output	Anode supply	Capacitance coefficients		
					AG	GK	AK
Telefunken Co.:—	watts	cm	watts	volts	cm	cm	cm
RS 224 (water-cooled)	10 000	580	1 000	5 000	27	18	5
RS 207g	1 500	300	200	3 000	12	10	5
RS 229 IIg	400	320	80	1 500	7	8	4
RS 19	200	290	25	2 000	7	5	2·5
RS 31 II	75	350	8	800	7	6·2	1·8
RS 55	25	240	4	600	8	6·2	1·4
RV 218 III	20	380	3	300	6	4·3	4·6
RS 24 I	12	340	2	275	7	5·0	3·2
REN 904	8	125	1	250	3·2	5·6	3·5
Métal. (Paris):—							
MC	80	180	5	800	4·5	1·9	1·2
TMC	12	100	0·8	600	2·9	1·6	0·9
General Electric Co. (U.S.A.):—							
UV 858* (water-cooled)	20 000	600	5 000	10 000	16·2	15·3	1·8
Author's construction:—							
Wassergek. V. (water-cooled)	2 000	320	650	4 000	9·2	5·8	3·0
Cyl. Anode	200	280	60	1 500	6·5	4·5	2·0
Hörner A	100	200	20	1 200	4·8	2·0	1·5
Hörner C	15	100	2·5	500	2·7	1·4	0·7

* For a full account of this valve see M. A. Acheson and H. F. Dart: "Characteristics of the UV-858 Power Tube for High-Frequency Operation," *Proceedings of the Institute of Radio Engineers*, 1932, vol. 20, p. 449.

(9) The Screen-Grid.

Experience with the triode, having shown that a perforated electrode could be inserted across the electron stream, controlling it while not intercepting it, showed no less that one or more additional grids could likewise be inserted. Multi-grid tubes can be used in various ways, but by far the most important use of an extra grid is to provide an electrostatic screen between anode and control grid. Since screen-grid receiving tetrodes became available 4 or 5 years ago, they have completely superseded triodes for all high-frequency amplification. The residual capacitance between anode and screen in receiving valves has been reduced to a few thousandths of 1 $\mu\mu$F, thus sensibly eliminating internal retro-action between the anode and grid circuits.

TABLE 4.

Amplification by Triodes and Tetrodes Compared.

Valve	Amplification factor, μ	Anode resistance, ρ	μ^2/ρ
		Ω	A/V
Triodes:			
H2 (2-volt)	35	35 000	0·035
MH4 (mains)	40	11 100	0·145
Screen-grid tetrodes:			
S22 (2-volt)	350	200 000	0·600
MS4 (mains)	550	500 000	0·600

The screening action of the screen grid depends, of course, not on the value of the screen potential but on its constancy. Actually in receiving valves the potential is given a high value somewhat below that of the anode. It has then little influence on the trans-conductance $g \equiv \frac{\partial i_a}{\partial e_g}$; but it necessarily decreases the anode conductance $\left(a \equiv \frac{\partial i_a}{\partial e_a}\right)$ *pari passu* with its screening action. (If the screen-grid mesh were made so fine that the grid-anode capacitance vanished altogether, the anode conductance a would also vanish.) A secondary effect of the screen in screen-grid tetrodes as used is, therefore, that the amplification factor μ and the anode resistance ρ are both much larger than in the triodes they replace. This is exhibited in Table 4, in which one maker's more or less corresponding triodes and tetrodes are compared. It is further illustrated, still more forcibly, in Fig. 23. Here on the same graph are the observed characteristics of a normal screen-grid tetrode and of a corresponding triode, one of the same factory batch exactly like the tetrode except that the screen-grid was omitted during assembly. The curves show that the introduction of the screen has left the trans-conductance g practically unchanged, while raising the anode resistance ρ some 8 times. The figure of merit, μ^2/ρ, is $0 \cdot 058$ A/V for the triode and $0 \cdot 48$ A/V for the tetrode. The latter therefore shows an improvement of 9 decibels. This happens to be nearly equal to the step of 10 decibels already noticed (with reference to Fig. 7) between the war-time triode and the battery-heated triode of to-day.

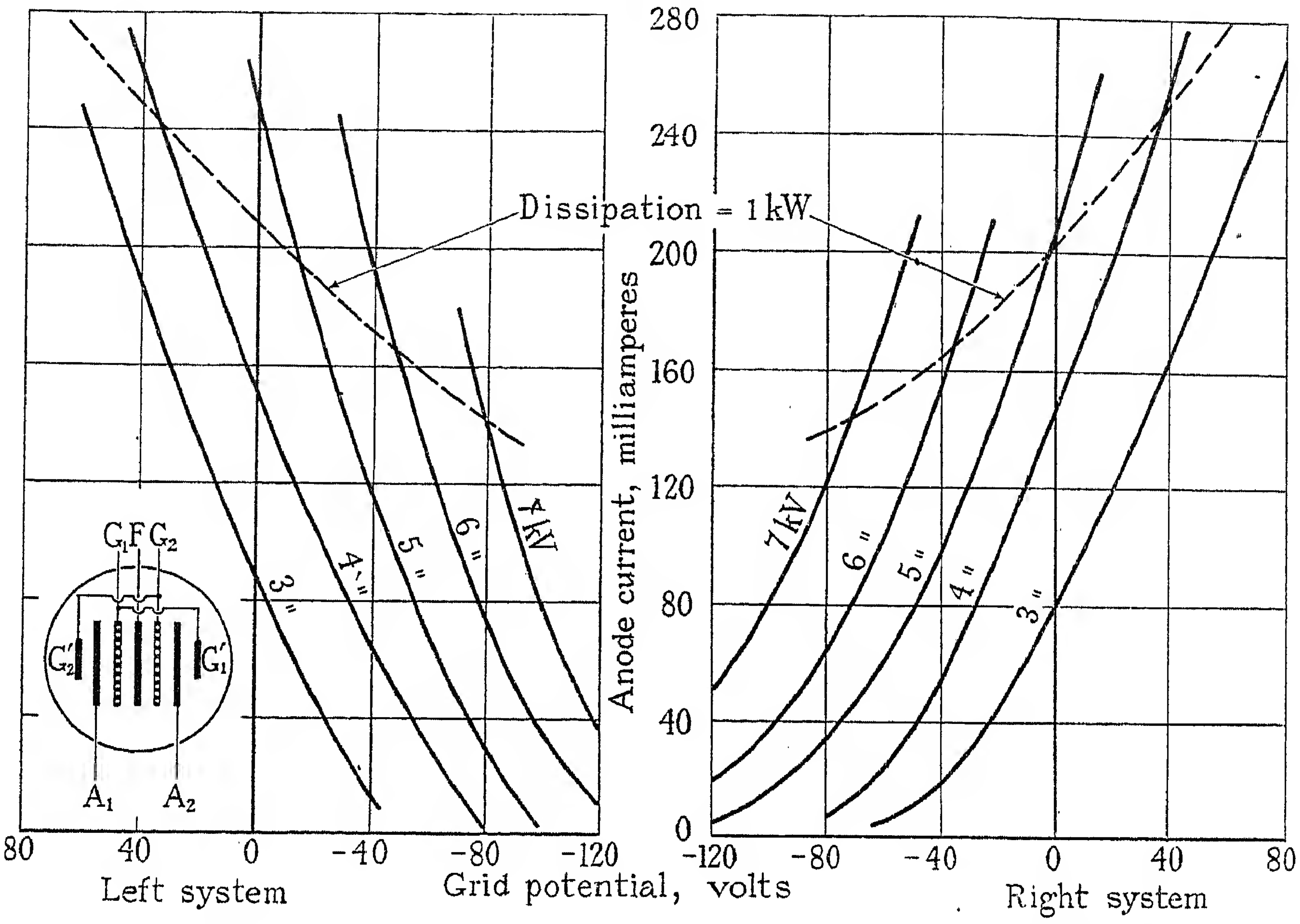


FIG. 22.—Static characteristics of silica heptode; anodes connected, grids connected.

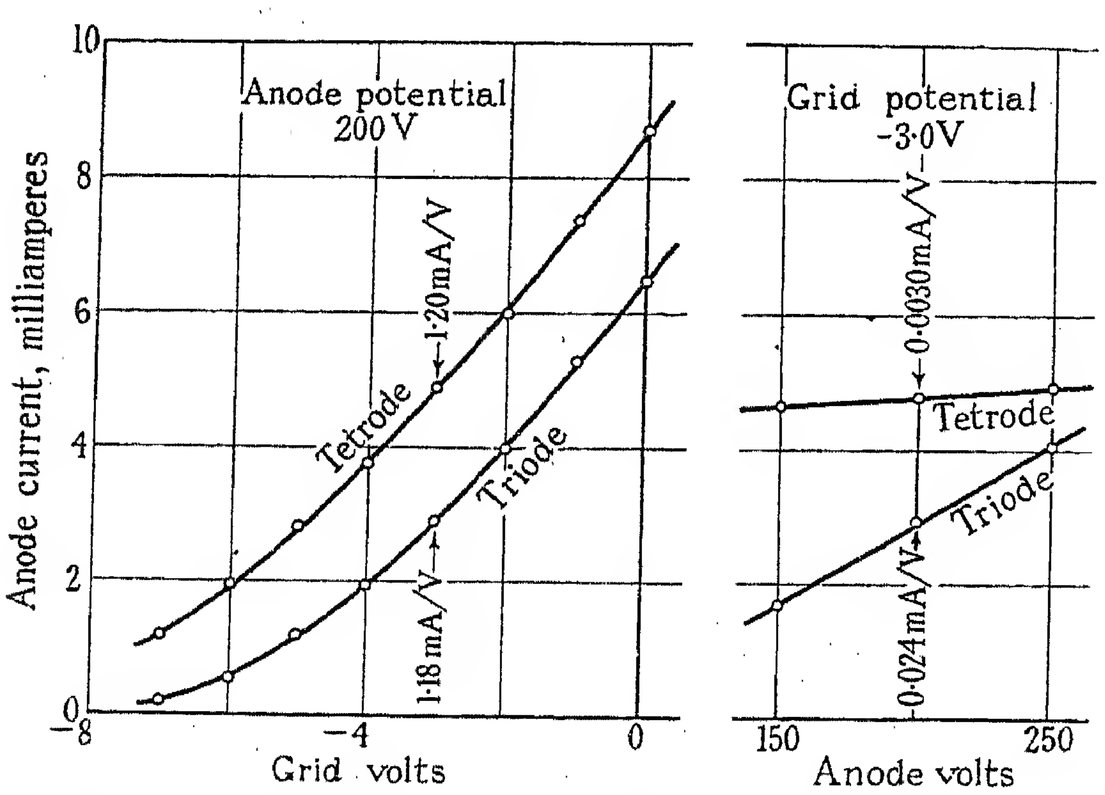


FIG. 23.—Effect of screen grid on characteristics.

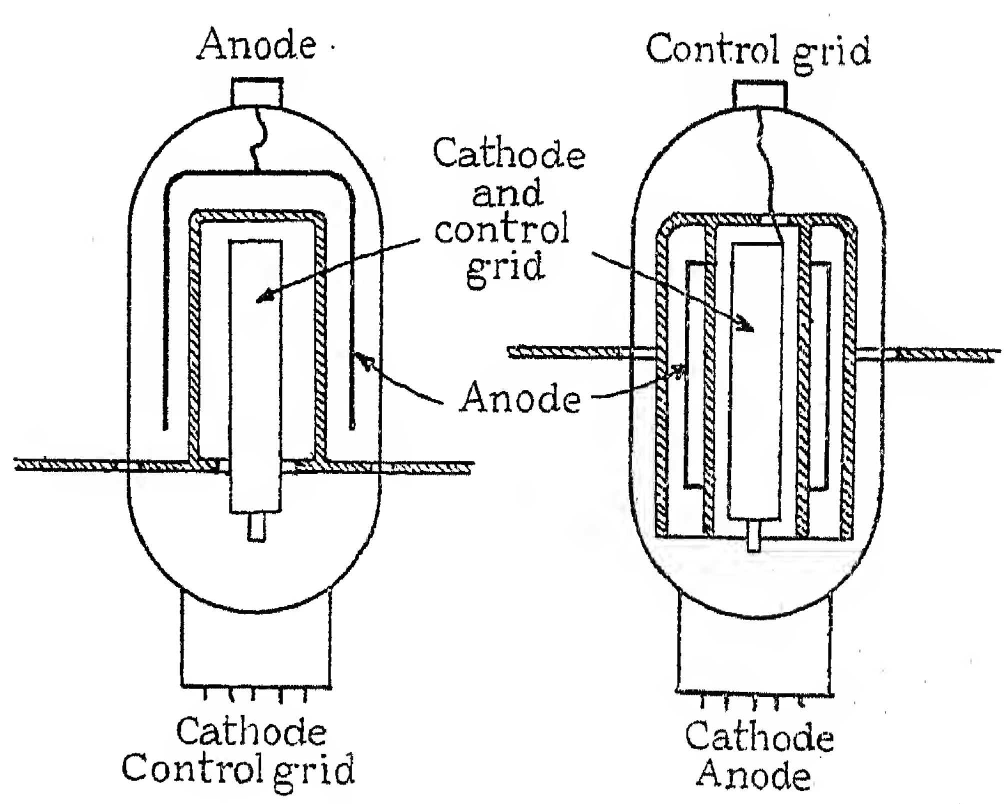


FIG. 24.—English (left) and American (right) screen-grid valves.

It is interesting in passing to contrast the typical English and American patterns of screen-grid valves. This is done diagrammatically in Fig. 24, where the screening grid, together with its plate-like extensions, appears as a box (shown hatched) in vertical section. In the English pattern, the cathode and control grid

are within the box (which is rectangular) and are connected to the pins; the anode plates are outside the box, and are connected to the top terminal. In the American pattern, the box (which is cylindrical) has double walls. In the central compartment are the cathode and control grid. The anode is in the annular outer compartment, the grid being connected to the top terminal. There seems to be as little technical ground for preferring either of these patterns as for preferring either of the standard heating supplies for indirectly heated cathodes, which are 4 V × 1 A in English and 2·5 V × 1·75 A in American valves.

(10) Secondary Emission.

The phenomenon of secondary emission—the liberation of secondary electrons from a cold electrode under bombardment by primary electrons—although present in diodes and triodes as ordinarily used, does not there

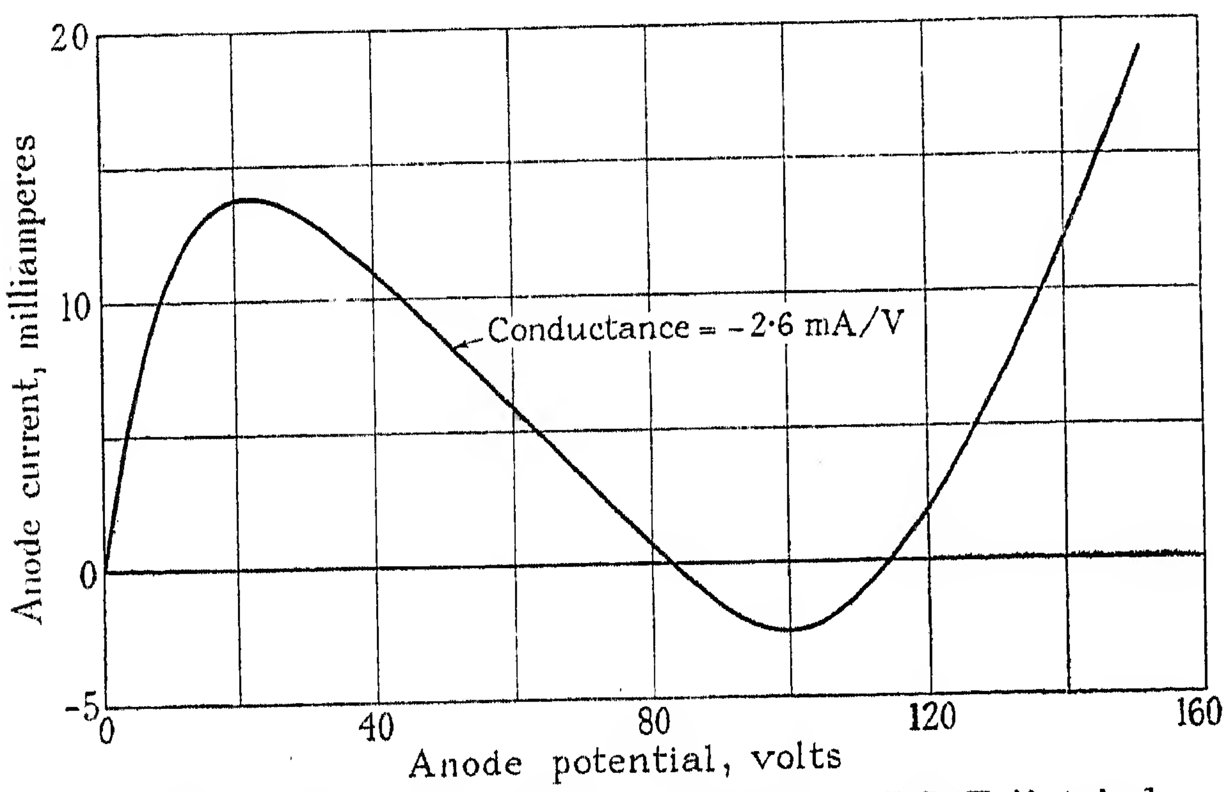


Fig. 25.—Dynatron effect in Osram "LS5B" triode (with de-gassed grid).
Filament p.d. = 4·2 V. Grid potential = 172 V.

make itself apparent. The reason is that the secondary electrons are emitted with speeds very much lower than that of the bombarding primary electrons, and are re-absorbed by the anode when the electric field in its neighbourhood is in the direction to urge them towards

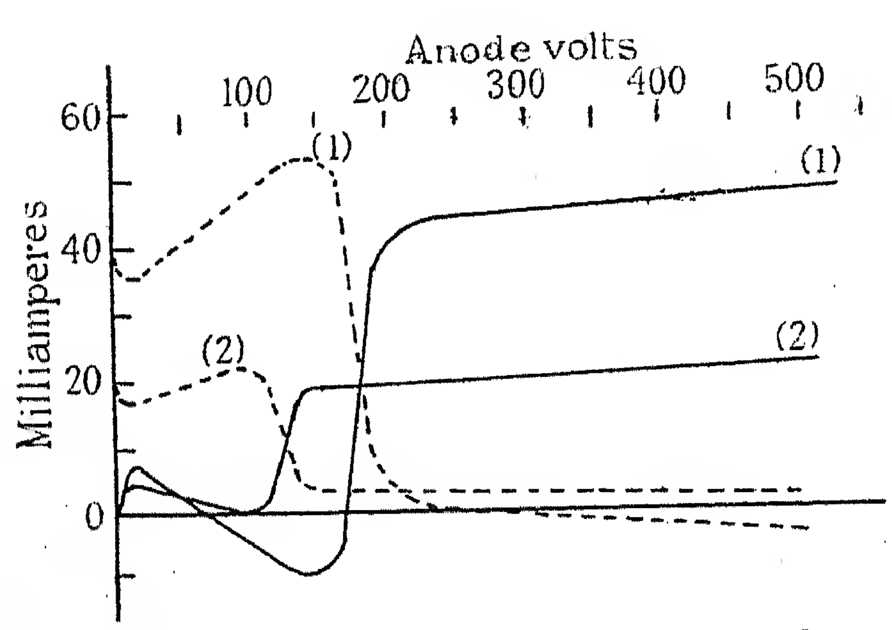


Fig. 26.—Screen-grid transmitting valve.
—— = anode current. – – – = screen current. Control grid = − 15 V. Screen: (1) = 175 V; (2) = 125 V.

the anode. If, however, the grid of a triode (or the grid next the anode, in a multi-grid valve) is given a potential above that of the anode, the secondary emission becomes very apparent, giving rise to the negative anode-filament conductance first utilized in the "dynatron" of A. W. Hull. Fig. 25 shows this effect in a receiving triode, and Fig. 26—from a paper by C. J. L. de la Sablonière*—shows the same effect in a screen-grid transmitting valve.

The easy production of quite large negative conductance without resort to oscillatory circuits or to retroaction has intriguing possibilities, but useful application of the phenomenon is hindered by the rather acute dependence of the amount of secondary emission on the surface condition of the bombarded electrode. Apart from minor applications in the laboratory, it is a troublesome rather than a useful phenomenon. To avoid its consequences, screen-grid tetrodes have to be worked under conditions ensuring that the anode potential shall never fall below the screen potential. In the pentode, now so popular in broadcast receivers, the additional low-potential grid next the anode is inserted to permit a larger anode swing.

(11) Screen-Grid Transmitting Valves.

The screen-grid principle has proved of great value when applied to the reception of high-frequency signals, and the question arises how far it can be adopted also in transmitting valves, where anode-grid capacitance is almost equally troublesome. Apart from added constructional complications, obvious unfavourable features introduced by the screen are the power consumed at the screen and the limitation on the swing of anode potential referred to above. Although neither of these objections has appreciable weight in receiving valves, in transmitting valves they call for a careful investigation of the optimum potential to be given to the screen. It is clear that the screen potential must not be as low as zero, since the anode current would then be nearly zero; and it must not be as high as the static anode potential, since any anode oscillation would then, during part of the cycle, produce the disastrous fall of anode current and rise of screen current illustrated in Fig. 26. Some value of screen potential lying between these limits will make the output a maximum. So much is evident, but any general analysis of the relations in a screen-grid oscillator or power amplifier is full of difficulties. It would seem that the design and best use of screen-grid power valves must for the present be largely empirical.

The choice of screen potential has been studied by Sablonière†, partly theoretically and partly with reference to the experimental behaviour of a particular valve. Sablonière finds that the screen potential giving maximum output is about half the static anode potential, but that some lower value is preferable for the sake of the higher efficiency then attained. It seems that a screen potential of the order of $\frac{1}{3}$ to $\frac{1}{5}$ of the static anode potential is usually adopted, and that efficiencies up to 60 per cent can be obtained.

As a power amplifier and frequency doubler for short-wave transmitters the screen-grid valve is likely to become very important. At present, however, it is at an early stage of development, and, as far as I am aware, with a single exception only quite small sizes have been constructed. The exception is a very interesting demountable tetrode, of the same general type as the

* "The Mode of Action of Screen-Grid Transmitting Valves," *Hochfrequenztechnik und Elektroakustik*, 1932, vol. 39, p. 191.
† *Loc. cit.*

demountable triodes already described. The anode is of 2·25 in. bore and 4·5 in. active length. The residual capacitance between the anode and the control grid is 0·5 $\mu\mu$F. When it is acting as a power amplifier at a wavelength of 10 m, the grid drive power is 600 watts, the anode feed 32 kW at 13 kV, and the efficiency 60 per cent.

(12) Time of Flight of Electrons.

Thus far, in our tour of thermionic devices, we have never had occasion to notice the time taken by the electrons on their journey from cathode to anode. This time may be short, but it must be finite. Actually, in small valves as ordinarily used the electrons take about 1/500 micro-second to reach the grid, and about one-tenth as long on their further journey to the anode.

The time of flight assumes importance when it reaches an appreciable fraction of the periodic time of the oscillation received or produced by the valve. It imposes a limit of 1 or 2 m on the wavelengths it is possible to generate by the usual retro-action between grid and anode circuits, but it also makes it possible to reach these and shorter wavelengths, down to a few centimetres, in quite a different fashion.

In a triode with the grid at a large positive potential and the anode at a small negative potential, electrons shot through the grid do not reach the anode but return to the cathode. If now a circuit between anode and cathode were in oscillation, electrons starting early in a positive half-cycle would be given an extra velocity towards the anode which might enable them to reach it even during the negative half-cycle. If the time of flight is something like half the oscillation period, there is here the possibility for electrons to deliver power (drawn from the grid battery) to the anode circuit in sufficient quantity to maintain the oscillations. This phenomenon, first described by Barkhausen and Kurz, is in fact observable without much difficulty, using a small receiving triode with tungsten filament and grid well freed from gas. Oscillations of this type have been produced with wavelengths well below 1 m, but their power is extremely small.

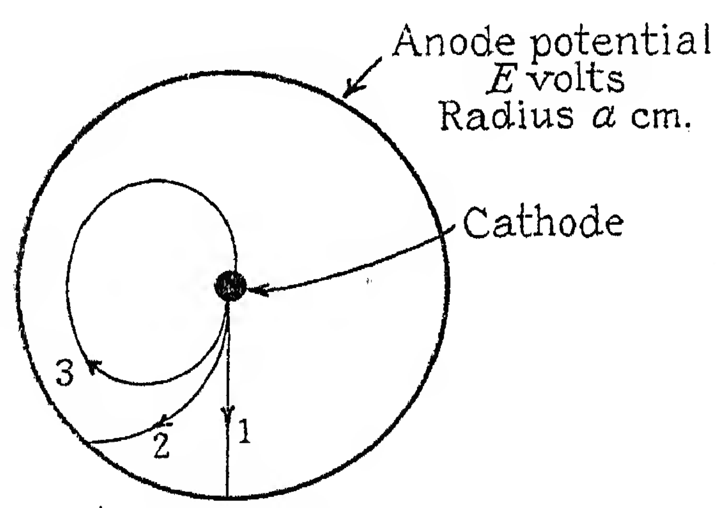


Fig. 27.—Magnetron.

Critical magnetic field $= 6 \cdot 72(\sqrt{E})/a$ C.G.S. units.
Then Time of flight to anode $= 0 \cdot 026a/(\sqrt{E})$ micro-seconds.

More powerful oscillations of still shorter wavelengths can be produced with the aid of a constant magnetic field so disposed as to deflect the moving electrons, thus determining whether and when they shall arrive at the anode. Fig. 27 is a view along the axis of a cylindrical diode. The anode is maintained at a high positive potential, and there is a constant axial magnetic field provided by a coil or magnet outside the envelope. An electron emitted at the cathode will follow path 1, path 2, or path 3 according to whether the magnetic field is absent, weak, or strong. For a given anode potential, there is a certain critical field strength H_c which makes curve 3 just touch the anode; any fall of anode potential will then inhibit anode current. Here, similarly, is the possibility of producing self-oscillation in a circuit between anode and cathode, and now, happily, without the former requirement of low anode potential. Such oscillators are called magnetron oscillators.

The magnetron offers the best hope of generating extremely high-frequency oscillations of tolerably high power. An improvement is a kind of push-pull development, in which the anode is split diametrically, the oscillatory circuit being connected between the halves. A split-anode magnetron is shown in Fig. 28. This

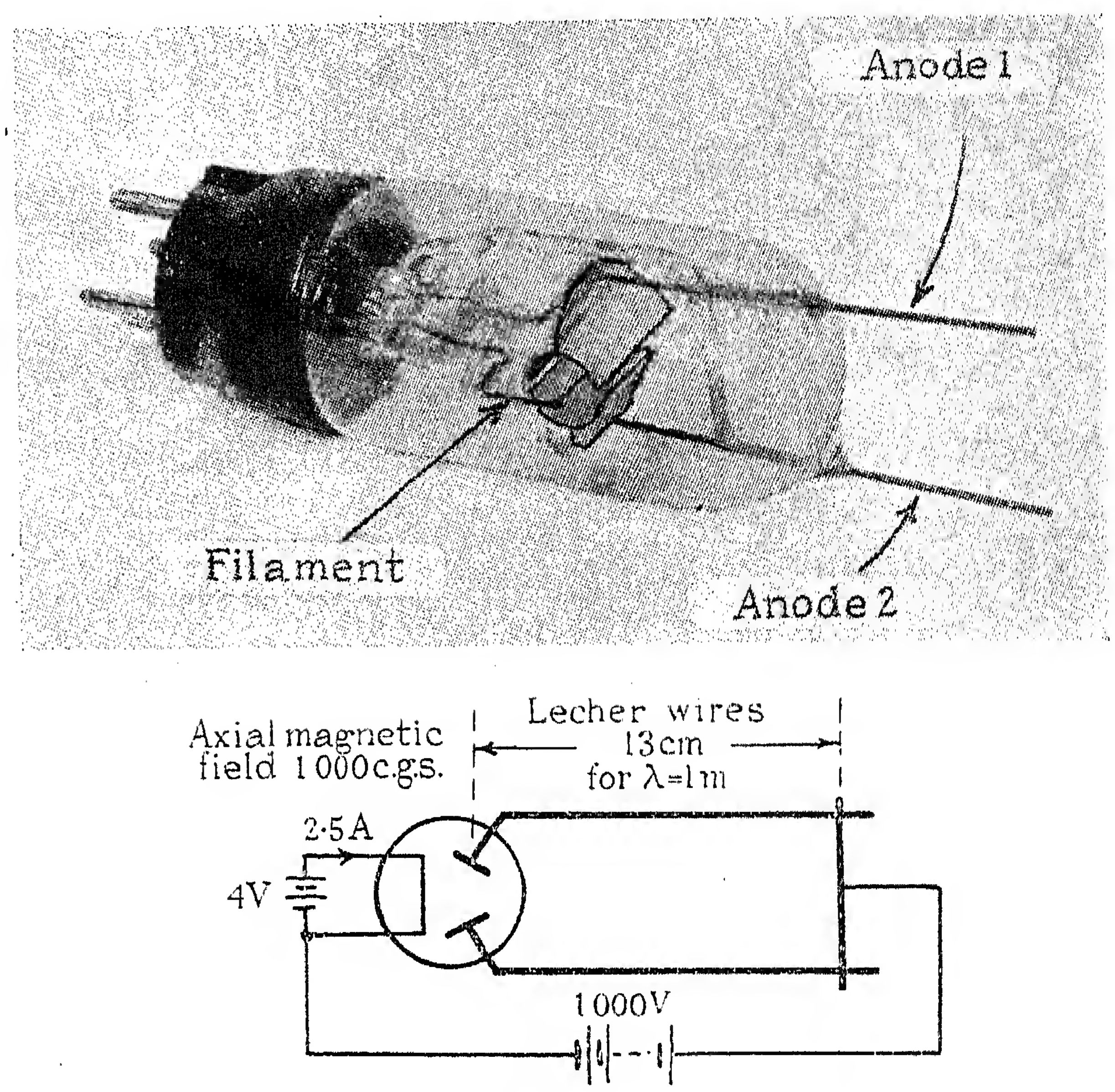


Fig. 28.—Split-anode magnetron.

valve is capable of an output of 10 watts at 1 m, and can be used to generate wavelengths down to 20 cm. The shortest waves yet generated by a valve appear to have been of wavelength 3 cm, and this figure was reached with a tiny magnetron oscillator.*

(13) Acknowledgments.

I should like to express my thanks for help received in the preparation of Part 1 of this Address. Material and information have come from many quarters. I gratefully acknowledge the courtesy shown me by the Post Office Engineering Department, the British Thomson-Houston Co., Messrs. A. C. Cossor, the Edison Swan Electric Co., the Metropolitan-Vickers Electrical Co., the Mullard Radio Valve Co., Philips Lamps, and Standard Telephones and Cables; and especially by Mr. C. C. Paterson and his staff at the Research Laboratories of the General Electric Co., Wembley.

* See W. H. Westrom: "Historical Review of Ultra-Short-Wave Progress," *Proceedings of the Institute of Radio Engineers*, 1932, vol. 20, p. 95.

Part 2. SPONTANEOUS FLUCTUATIONS IN VALVE AMPLIFIERS.

(1) The Existence of Amplifier Limits.

I think it will generally be agreed that, of all the applications of thermionic valves to-day, the most indispensable are the production of oscillation of short wavelengths and the amplification of weak signals. In both these applications endeavours have been, and are being, made to push ever further the limit of practicable performance: in the one, to produce still shorter waves, and in the other to amplify still weaker signals. For extremely short waves, it has been found necessary to change the method of using the valve—e.g. to abandon the retro-acted triode in favour of the magnetron type of oscillator. For the amplifying of extremely weak signals, on the other hand, although definite theoretical limits exist and have been reached experimentally, no change of method has so far been suggested. I purpose now to discuss the limits in the weakness of signals which can profitably be applied to an amplifier.

In 1918 high-vacuum valve technique had been carried far enough for amplifiers of great sensitivity to be constructed, and the spontaneous "noise" generated within such instruments had become troublesome. In that year, in a very notable paper entitled "On Spontaneous Fluctuations of Current in Electrical Conductors," W. Schottky* deduced from the accepted theories of matter and electricity that two types of spontaneous fluctuations must be present in any valve amplifier. Later J. B. Johnson†, in the course of an examination of the Schottky effect, showed empirically the occurrence of a third, quite distinct, type of fluctuation. The existence of these internal disturbances, however minute they may be, appears to impose an impassable obstacle to the continued development of the amplifier in its role of electrical microscope.

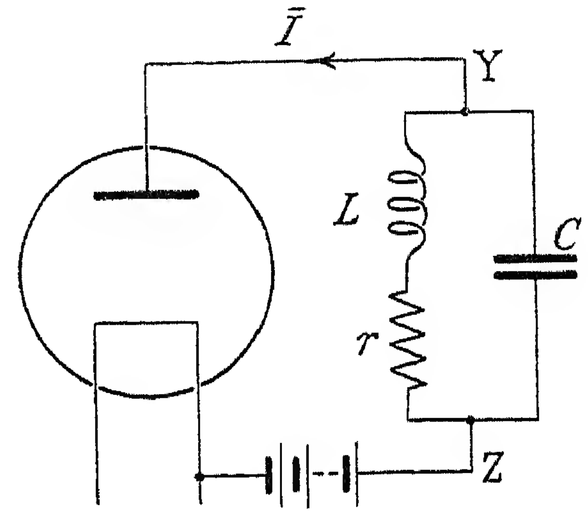
(2) Shot Effect.

If electricity is atomic in nature, the current in a high-vacuum thermionic tube—or, indeed, anywhere else—cannot be a uniform flow. It must be a hail of discrete particles, like the arrival of the cloud of small shot from a gun, whence the name "shot effect" is taken. When we speak of the current at any instant, it must be with some statistical reference, as when we speak of the country's birth-rate on a specified date. Now the mean separation between two electrons emitted from the cathode nearly simultaneously is very many diameters of the atom, and it is reasonable to assume that the flight of any electron is independent of the flight of any other electron (in the sense that the fall of a raindrop here is independent of the fall of a raindrop there). It follows that the rate of arrival of electrons obeys the probability law for a disorderly time-distribution of equal elementary events. In a succession of time intervals τ, there arrive sometimes more and sometimes less than the mean number. The smaller τ is, the more widely does the number of arrivals

* *Annalen der Physik*, 1918, vol. 57, p. 541.
† "The Schottky Effect in Low-Frequency Circuits," *Physical Review*, 1925, vol. 26, p. 71.

fluctuate. It seems that the only magnitude which can be assigned to the current thus constituted is its mean square value over a long time, and even this can be calculated only on some assumption as to the manner of emission at the cathode.

T. C. Fry,* in a searching analysis of the shot effect, in which certain clearly-defined assumptions have to be made, arrives at a result† shown substantially in Fig. 29,

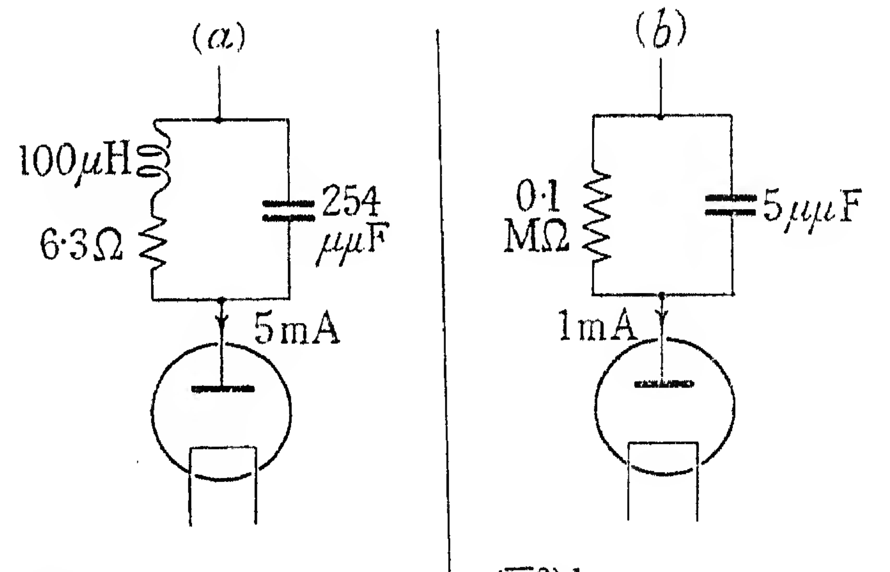


$$\overline{E_s^2} = \frac{q_e \bar{I}}{2} \cdot \frac{L + Cr^2}{C^2 r}$$

Fig. 29.—Schottky's Schroteffekt or shot effect.

where $\overline{E_s^2}$ is the mean-square potential difference across YZ due to shot effect, and q_e is the electron charge. The analysis relates to a temperature-saturated flow, in which, therefore, space-charge is sensibly absent. When L, r, C, are dimensioned for radio frequencies, the formula is found to agree closely with measurements.

To get an idea of the magnitude of the shot effect, let us take (*a*) an anode circuit sharply tunable to a wavelength of 300 m, and (*b*) an anode circuit as in a resistance amplifier. Fig. 30 shows the dimensions of circuits (*a*) and (*b*), and the R.M.S. value $(\overline{E_s^2})^{\frac{1}{2}}$ of the



$(\overline{E_s^2})^{\frac{1}{2}} = 3{\cdot}1 \times 10^{-4}$ V. | $(\overline{E_s^2})^{\frac{1}{2}} = 8{\cdot}1 \times 10^{-4}$ V.

Fig. 30.—Shot effect: numerical examples.

potential difference produced across them by the shot effect.

If the same spontaneous fluctuations occurred with LrC (Fig. 29) in the anode circuit of a valve amplifier giving, say, an amplification of 100 to an appropriate signal applied to the grid, a power equal only to that already caused by the shot effect would be introduced by a signal of strength (*a*) 3 μV, (*b*) 8 μV; so that signals such as these would be drowned by the shot effect. In practice, however, signals considerably weaker than these are sometimes applied to amplifiers with success.

* "The Theory of the Schroteffekt," *Journal of the Franklin Institute*, 1925, vol. 199, p. 203.
† J. B. Johnson: "Schottky Effect in Low-Frequency Circuits," *Physical Review*, 1925, vol. 26, p. 74.

The explanation, at least partly, is that in an amplifier the current is necessarily space-charge limited in order that it may be subject to control by the grid, and experiment has shown that the shot effect is much reduced by the presence of a space charge. The theory of this reduction does not appear to have been worked out, but the reduction factor in $\overline{E_s^2}$ may amount to $\frac{1}{50}$ in diodes and to $\frac{1}{3}$ or $\frac{1}{5}$ in triodes.*

(3) Flicker Effect.

When the measuring system LrC (Fig. 29) by which the shot effect is observed is given dimensions to suit signal frequencies below about 1 kilocycle per sec., and especially when the anode current is made large, the mean-square potential difference which develops spontaneously across it is sometimes found to be 100 to 1 000 times greater than that given by the Schottky-Fry formula. It seems certain that there is another, and quite unrelated, source of fluctuation. This is known as the flicker effect. In some tubes it may be due partly to ionization of residual gas, but where the vacuum is good it is probably to be attributed to the emission of positive ions by the cathode, and to the appearance on the emitting surface of foreign atoms whose average length of stay is some 0·001 sec. on oxide-coated filaments, and upwards of 0·05 sec. on tungsten filaments†. It is known that a single layer of atoms may raise or lower the emission a thousandfold, and it is at least probable that there is an incessant migration amongst the atoms on the incandescent emitting surface.

Whereas the shot effect is proportional to the current, the flicker effect is proportional to the current squared. The shot effect depends on the random time-distribution of events, each of which is the emission of one electron; it is due to the atomicity of electricity. The flicker effect depends on the random distribution of events each of which is the introduction or suppression of a great block of electron emissions; it is due to the atomicity of matter. The flicker effect, like the shot effect, is much reduced by the interposition of a space-charge between the cathode and the anode. Improvements in the cathode may, it is conceivable, reduce or remove the effect. Nevertheless, the limit for signals of low frequency has hitherto been imposed by flicker effect. It is claimed, however, in a very recent publication‡ that—by special attention to certain details of the valve—flicker effect has been sensibly abolished, and that consequently the shot effect is left as imposing the limit, even in amplifiers for frequencies below 100 cycles per sec.

(4) Temperature Effect.

The third type of spontaneous fluctuation in amplifiers is at once the most serious in practice and the best understood in theory. Its origin lies outside the valve altogether, and it was revealed experimentally by the valve only because valve amplifiers provided for the first time an observing instrument of sufficient delicacy to make the effect perceptible. It is due to the random motion of the electrons within a conductor in thermodynamic equilibrium with the molecular agitation (which we call temperature), and it may therefore be termed briefly the temperature effect.

What do we mean when we say of a length of wire AB, carrying no current, that the potential difference between A and B is zero? We mean much the same as when we say of the tube AB in Fig. 31 that the force exerted by the gas on end A is equal and opposite to the force on end B, so that the tube hangs still. Again, however, these "forces" are mere abstractions. Actually end A undergoes a random bombardment of discrete molecules, and so does B; how completely these bombardments will cancel out can be stated only in statistical terms. With acute enough vision, we should see that the tube is wobbling about. The way it wobbles depends on the properties of the tube and strings, as well as on the nature of the agitation of the molecules of the gas.

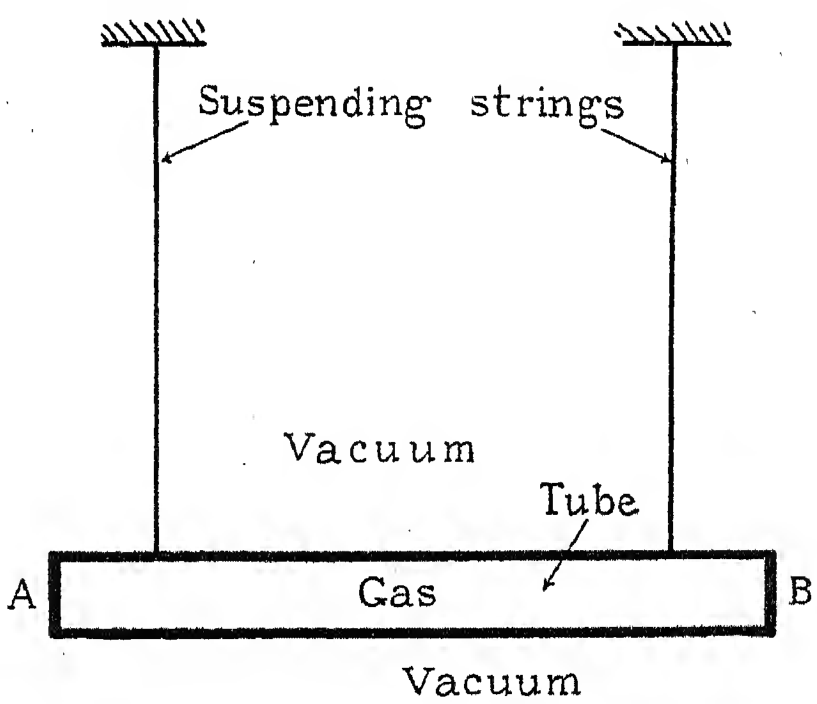


Fig. 31.—Statistical equilibrium.

A cubic centimetre of conducting material—say, copper—at room temperature contains a great number (about 10^{22}) of free electrons in thermal agitation amongst a great number of molecules. The kinetic theory requires that the average kinetic energy of an electron, as of a molecule, shall be $\frac{3}{2}\kappa T$, where κ is the universal Boltzman constant ($1 \cdot 372 \times 10^{-16}$ ergs per deg. C.), and T is the absolute temperature on the Centigrade scale. κ may be more familiar as the constant in the Boyle-Charles law,

$$pv = \kappa NT$$

for the pressure and volume of N molecules of a perfect gas. It follows that at room temperature the electrons are bouncing about with an average R.M.S. speed of about 12×10^6 cm per sec. This must be regarded as an enormous speed, because of the enormous ratio it bears to the average speed of drift of the electrons which constitutes a current. This speed of drift is about 0·1 cm per sec. when the current density is 1 000 amperes per sq. in. What we ordinarily call zero current in a conductor must be regarded as the sum of a great number of independent currents, whose mean square value is enormous, but whose mean value tends to zero owing to their random signs and magnitudes.

Expressed in terms of potential difference across the

* W. Schottky: "Small-shot and Flicker Effects," *Physical Review*, 1926, vol. 28, p. 75.
† W. Schottky: *Loc. cit.*
‡ Metcalfe and Dickinson: "A New Low-Noise Vacuum Tube," *Physics*, 1932, vol. 3, p. 11.

ends of the conductor, the temperature effect consists of a continuous spectrum, or Fourier integral, of potential difference, containing terms of every frequency, all of equal amplitude. The mean square of the terms lying within any frequency range δn, is given by

$$\overline{E}_t^2 = 4\kappa RT\ \delta n^*$$

where R is the resistance of the conductor as measured

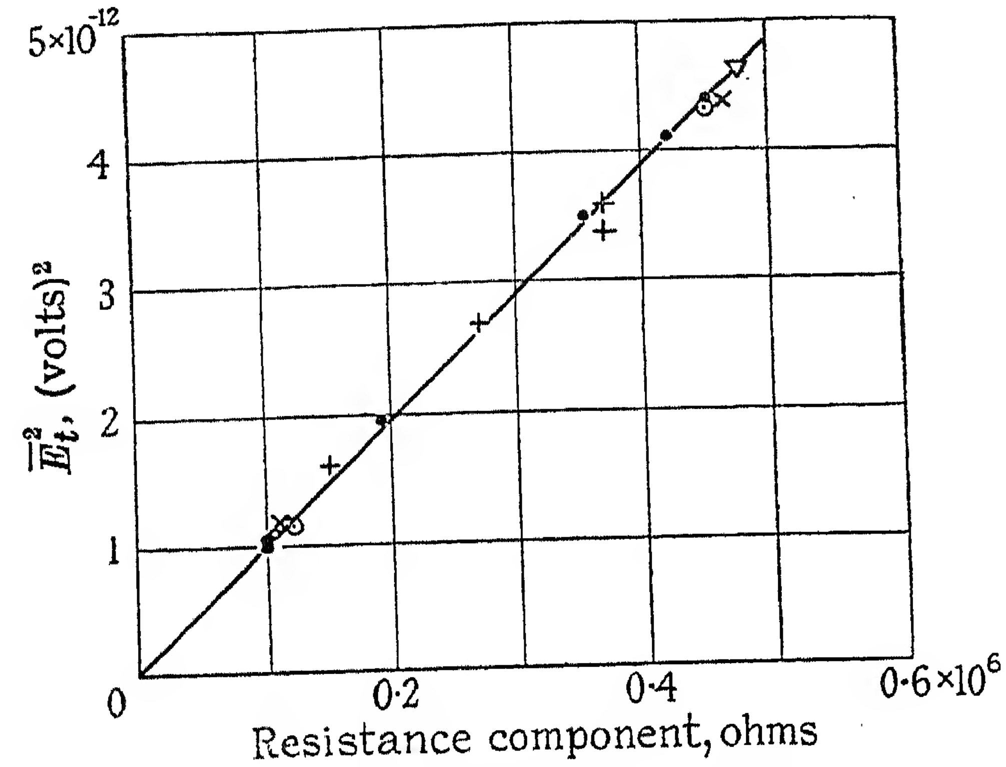


FIG. 32.—Temperature effect in various resistances.

● Carbon filament. + Advance wire. × $CuSO_4$ in water. ▽ NaCl in water. ⊙ K_2CrO_4 in water. ○ $Co(NO_3)_2$ in water.

in the ordinary way (macroscopically). If the impedance of the conductor for any frequency is not a pure resistance, but must be regarded as a network comprising inductance and capacitance (which, of course, every real conductor is), then R in the above formula must be replaced by the real term in the complex impedance.

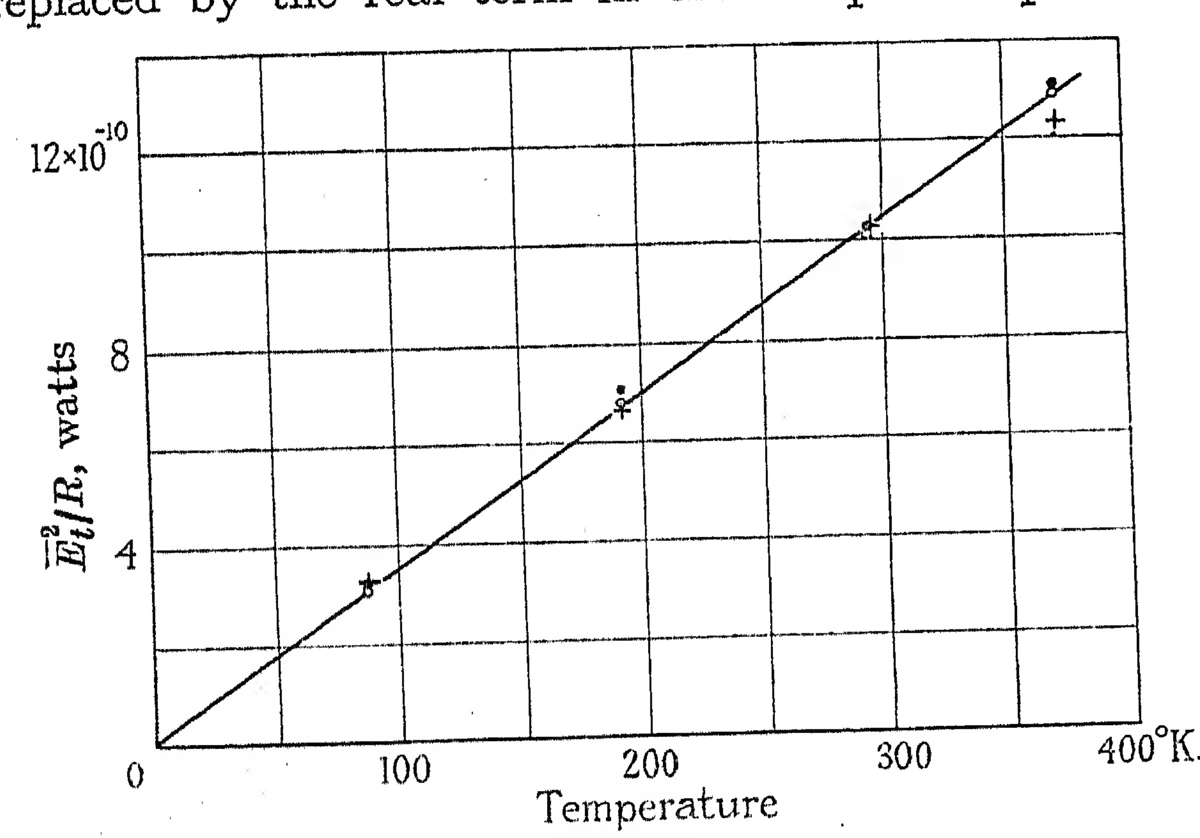


FIG. 33.—Temperature effect at various temperatures.

● $R = 0\cdot 15 \times 10^6$ ohms.
○ $R = 0\cdot 29 \times 10^6$ ohms.
+ $R = 0\cdot 44 \times 10^6$ ohms.

For room temperature 293° K., with microvolt, megohm, and second units, the formula is

$$\overline{E}_t^2 = 0\cdot 0161 R\ \delta n$$

The accuracy of the temperature-effect theory is substantiated by some beautiful experiments which were made by J. B. Johnson† in 1928, and with greater precision this year by H. D. Ellis and E. B. Moullin,* who used their observations of the temperature effect to measure the Boltzmann constant κ in our formula. Ellis and Moullin arrive at a result differing by only 0·8 per cent from the accepted value.

That the effect really is *linearly* proportional to the value of the resistance, without respect to the nature of the material, is strikingly shown by Fig. 32, which is reproduced from Johnson's paper. That it is *linearly* proportional to the temperature is shown by Fig. 33, which is also reproduced from his paper.

We are concerned with the effect of this temperature potential-difference on the output of an amplifier. Now when we examine a continuous spectrum we find whatever we look for. If I look at the sun through one piece of glass I see blue; through another, red. But the sun is neither blue nor red; the colour is provided by my observing apparatus. If I hold a large sea-shell to my ear, I hear an intriguing note; but this is not the music of the spheres, nor even of the sea. The shell itself selects an order, according to its shape and size, from the random disturbances which fill the atmosphere. So, when the temperature potential difference across a conductor is applied to an amplifier, a disturbance is produced which depends on the frequency-response quality of the amplifier.

Consider the amplifier shown in Fig. 34, in which as a numerical example we will suppose that W is a grid leak of 1 MΩ at a room temperature of 20° C. ($T = 293°$ K.), and K is a small stray capacitance of 10 $\mu\mu$F. The resistance R of the network AB depends upon frequency according to the formula

$$R = \frac{W}{1 + 4\pi^2 f^2 K^2 W^2}$$

In the top curve this, multiplied by $4\kappa T$, is plotted against f, and so shows the mean-square potential difference per unit frequency interval produced across AB. The amplification

$$m \equiv \frac{\text{Potential difference at YZ}}{\text{Potential difference at AB}}$$

also depends upon frequency, and in the bottom curve m^2 is plotted against frequency for the assumed amplifier.† The middle (dotted) curve is constructed with ordinates equal to the product of the ordinates of the other curves. Then any areas‡ under the curves, such as those shown shaded in the figure, are the mean-square potential difference across AB or across YZ within the frequency range upon which they stand: in Fig. 34 this range is 6 to 7 kilocycles per sec.

Thus if an electrostatic voltmeter (or some more sensitive equivalent), provided with a band-pass filter cutting off sharply at 6 kilocycles per sec. and at 7 kilocycles per sec. were connected across YZ, its reading would be the square root of the lower shaded area: this is about 1·8 mV. If the filter were omitted, the reading

* H. NYQUIST: "Thermal Agitation of Electric Charge in Conductors," *Physical Review*, 1928, vol. 32, p. 110.

† "The Thermal Agitation of Electricity in Conductors," *Physical Review*, 1928, vol. 32, p. 97.

* "A Measurement of Boltzmann's Constant by means of the Fluctuations of Electron Pressure in a Conductor," *Proceedings of the Cambridge Philosophical Society*, 1932, vol. 28, p. 386.

† Actually this curve shows the measured performance of the acoustic part of my own broadcast receiver when loaded with its loud-speaker.

‡ Evaluated, of course, according to the scale markings: in these curves the abscissæ are logarithmic.

would be the square root of the whole area beneath the dotted curve extended from $f = 0$ to $f = \infty$: this is about 6·9 mV. Since m^2 at, say, 1 kilocycle per sec. is seen to be $2 \cdot 6 \times 10^5$, the same reading of 6·9 mV would be produced by an input signal of frequency 1 kilocycle per sec. and of strength

$$\frac{6 \cdot 9}{\sqrt{(2 \cdot 6 \times 10^5)}} \text{ mV} = 13 \cdot 5 \, \mu\text{V}$$

These calculations show that the temperature effect imposes an appreciable limitation on the weakness of signal which can be dealt with by any amplifier covering a wide range of frequency, as any amplifier for faithful acoustic performance obviously must. It is not possible to dodge this difficulty by amplifying an acoustically-modulated high-frequency carrier instead of the acoustic signal itself. The disturbance is proportional to the width of the frequency band, whether this band extends, say, from 50 to 5 000 cycles per sec. or from $(10^6 + 50)$ to $(10^6 + 5\,000)$ cycles per sec. Consideration of the temperature effect adds another to the many arguments for designing a receiver of any sort to have the narrowest sensitive frequency band permitted by the particular service it is required to render.

With regard to the input network AB in Fig. 34, this, of course, is not always a grid leak, but is chosen according to the duties of the amplifier. In practical conditions the aim is to devise an amplifier usefully operated by very small input power rather than input potential difference. Since the temperature effect $\overline{E_t^2}$ is itself proportional to R, however, the power $\overline{E_t^2}/R$ cannot be reduced even by reducing R. When planning an amplifier to respond throughout a limited but not very narrow band of frequencies, in order to keep the signal input impedance large and the temperature effect small, the most favourable form of the AB path (Fig. 34) is an inductance coil of large reactance to the signal frequencies, and of the smallest possible resistance, with the smallest possible stray capacitance. The difficulties of realizing these largely inconsistent aims are so familiar, without reference to the temperature effect, that I need not dwell upon them.

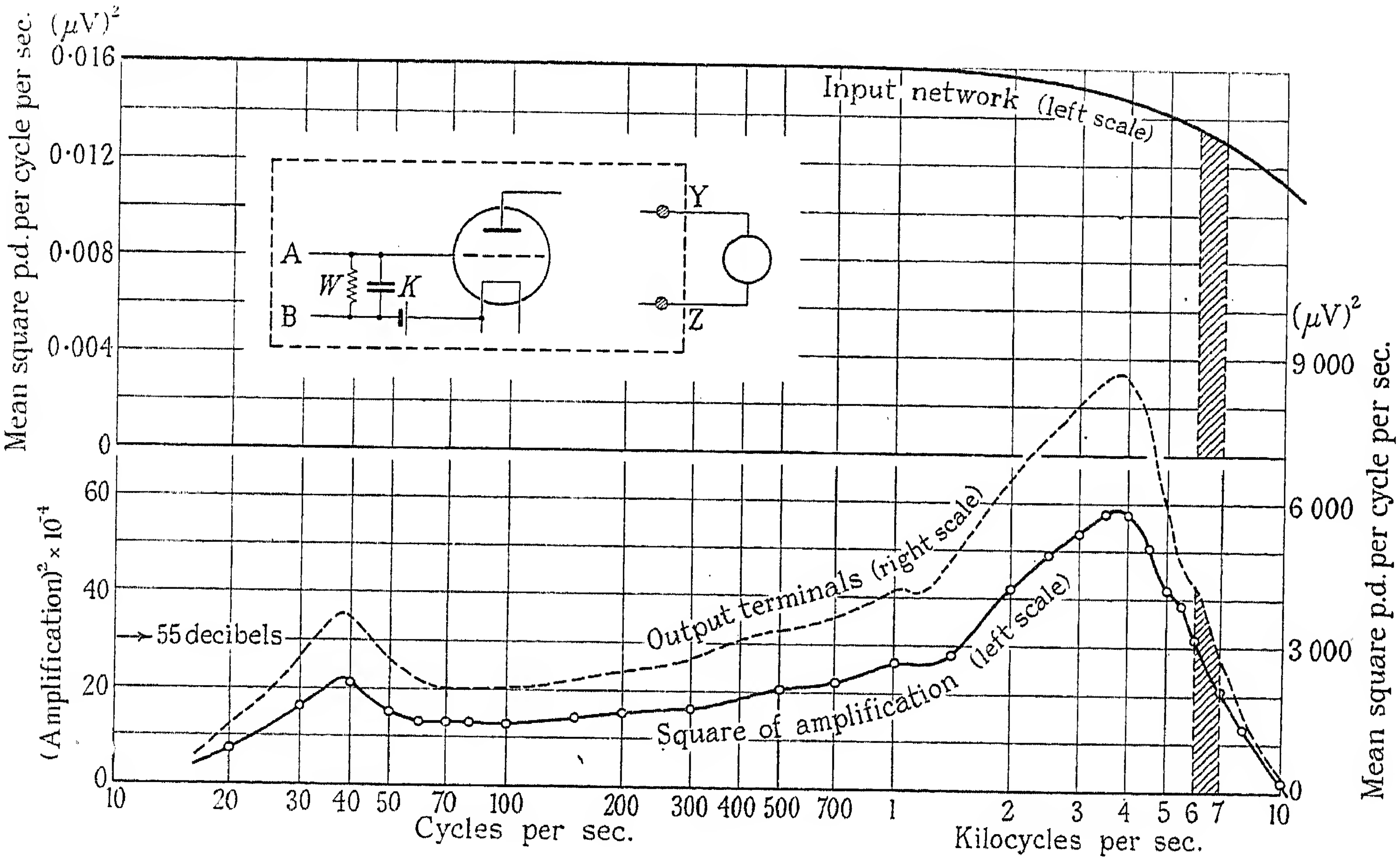


FIG. 34.—Temperature effect in first grid leak of multi-stage amplifier.

(5) ESTIMATES OF PRACTICAL LIMITS.

To wind up this account of the valve as an instrument of extreme delicacy, I shall quote a few estimates and experimental determinations of how far it is practicable to go in the present state of the art.

(i) A broadcast receiver of ordinary sensitivity may require an amplitude on the grid of some 10 μV to work it satisfactorily.*

(ii) In their recent investigations Moullin and Ellis† used an amplifier for frequencies around 2 kilocycles per sec. which was moderately selective, the power (or square of amplification) falling to $\frac{1}{10}$ on detuning 25 per cent from resonance. The temperature effect in a resistance of 0·1 MΩ at the first grid produced a galvanometer deflection equal to that given by a tuned signal input of 0·7 μV. Removing the temperature effect by short-circuiting the grid resistance left a residue of amplifier disturbance (including shot and flicker effects) representable by a tuned input signal of 0·13 μV.

(iii) As a practical guide for voice-range amplifiers, J. B. Johnson‡ gives figures expressible thus. When temperature effect on the first grid is short-circuited out, the residual amplifier disturbance is equal to the effect of an input signal of 0·6 μV. (Compare Moullin and Ellis's figure of 0·13 μV in their more selective amplifier.)

(iv) I have interesting particulars, kindly given me by Mr. B. S. Cohen, of a sensitive wide-band amplifier constructed by the Post Office Research Department

* S. BALLANTINE: "Fluctuation Noise in Receivers," *Proceedings of the Institute of Radio Engineers*, 1932, vol. 18, p. 1379.
† *Loc. cit.*
‡ *Loc. cit.*

for cross-talk and other telephonic measurements. The amplifier is shown in Fig. 35, together with a curve giving the amplification between the "OUT" and the "IN" terminals. For the valve system alone—i.e. first grid to last anode—a gain of 10 decibels, the net gain in the two transformers, must be subtracted from the ordinates of the curve. The amplification was measured with an output of 1 volt, which, when the gain is 100 decibels, corresponds with an input of 10 μV; but, in the absence of spontaneous disturbances, the apparatus would be sensitive enough to give a galvanometer deflection of 2 cm with an input signal of $0 \cdot 1$ μV. The strength of the weakest input signal with which the amplifier has so far been used is $0 \cdot 2$ μV (at 800 cycles per sec.), and in this condition the deflection of the galvanometer was about $2 \cdot 5$ times as great when the signal was applied as when the "IN" terminals were short-circuited. This implies that the disturbance alone was equivalent to an input signal of about $0 \cdot 16$ μV, i.e. $3 \cdot 8$ μV on the first grid.

Their experience with the instrument inclined the Post Office engineers to attribute this mainly to residual stray fields penetrating the screen, but further investigation would be required to settle the point. Meanwhile, our formula shows that a resistance of 45 000 ohms between the first grid and filament would produce by temperature effect within (say) a frequency band of 20 kilocycles per sec. a potential difference of $3 \cdot 8$ μV (R.M.S.). It seems, therefore, that temperature effect within the transformer may well be responsible for the disturbance.

(v) A. W. Hull* puts the limit of smallness of voltage amplifiable as 1 μV at high frequency, but he does not specify how selective a circuit he contemplates. He remarks that at low frequencies what we have called the flicker effect may cause much greater fluctuations; but that as, quite recently, these fluctuations have been very much reduced in the special valves of Metcalfe and Dickinson to which I have already referred, it may now prove possible to work down to $0 \cdot 1$ μV at low frequencies. This suggested low-frequency figure ($0 \cdot 1$ μV) is smaller than his high-frequency figure (1 μV), presumably because, within limits, the lower the frequency the narrower can the sensitive frequency band be made. It is much easier to differentiate between, say, 1 000 and 1 200 cycles per sec. than between, say, 10^6 and $(10^6 + 200)$ cycles per sec. I think Hull here has in mind a band of width 200 cycles per sec. for low frequencies.

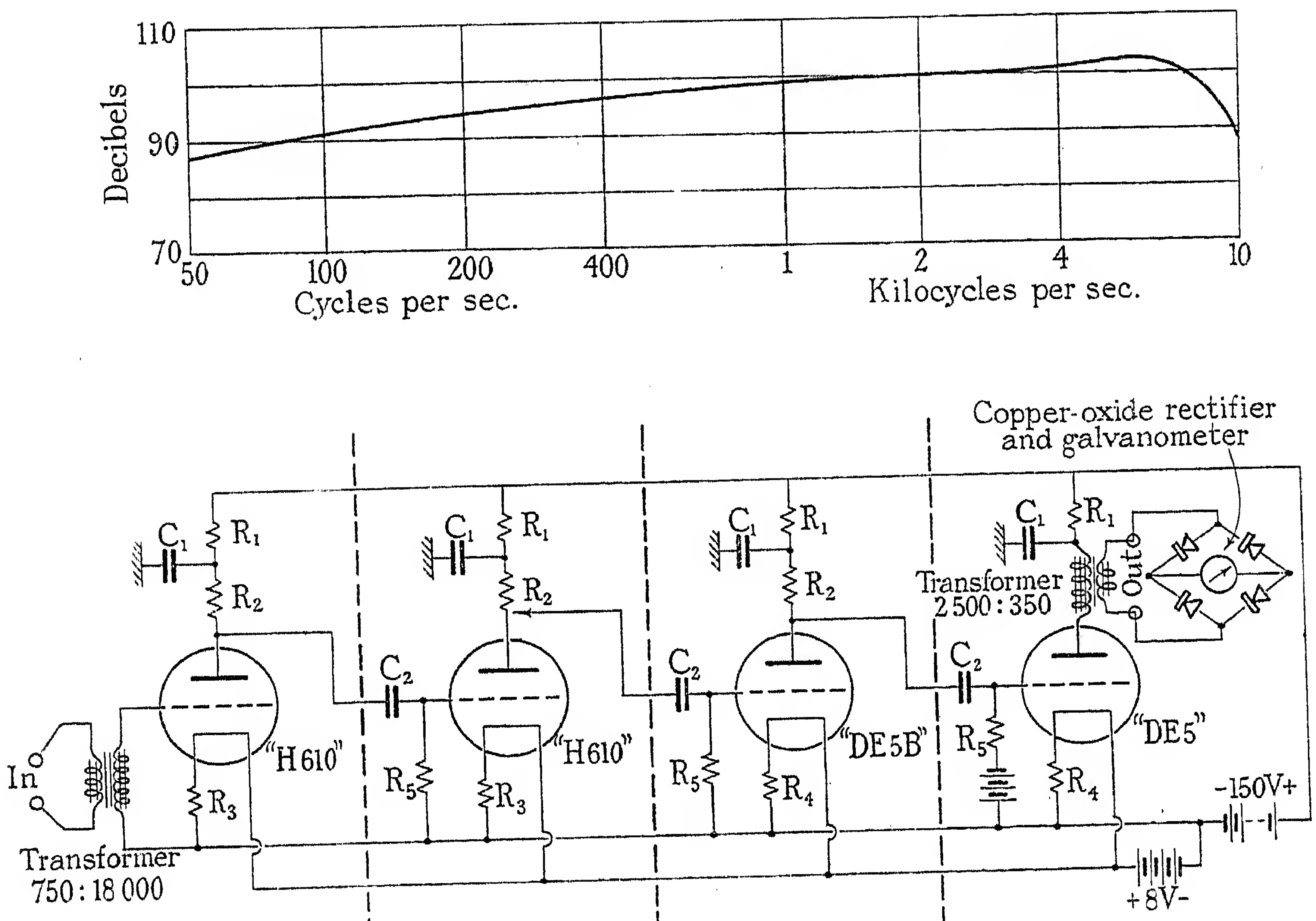


FIG. 35.—Sensitive acoustic-frequency amplifier.

$R_1 = 20\,000\ \Omega$. $R_3 = 20\ \Omega$. $R_2 = 200\,000\ \Omega$. $R_4 = 8\ \Omega$. $R_5 = 1\ M\Omega$.
$C_1 = 2\ \mu F$. $C_2 = 0 \cdot 1\ \mu F$.
Electrostatic screen.

(vi) The same author, in describing the use of an electrometer valve in association with a photo-electric cell for stellar photometry, quotes a report from Yerkes Observatory that it was possible to detect currents—i.e. through the photo-cell to the grid terminal of the amplifier—down to 10^{-16} ampere, corresponding to the current caused by the light from a star of the fourteenth magnitude.

(6) CONCLUSION.

I have been trying to review what is, perhaps, the sublimest function of the valve—its application to the detection and measurement of the limitingly small. This has not taken us out of the domain of engineering, for our very lamps are now graded for market by the photo-cell and electrometer valve; but it has forced us

* "Electronic Devices as Aids to Research," *Physics*, 1932, vol. 2, p. 419.

to contemplate the innermost recesses of the material world, as we imagine it, where reality is a word without much meaning. An engineer—a doer, one who works quickly and in the rough—expects to find only a fair agreement between his observations and those laws of physics on which his calculations rest. He is, however, wont to suppose comfortably that the agreement would become ever closer the more care he put into the experiment. Here, on the contrary, he is shocked to find signs of disorder growing more sure with the improvement of experimental precision. If this moment were a hundred years earlier, there might be those in my audience to exclaim that God, who gave us eyes and fingers measured in inches, did not mean us so to pry into his mechanisms, to discern the discontinuities in their smoothness. A century ago, however, Democritus and Dalton had done their impious work, in idea. To-day we carry it further, but now in the laboratory and even in the workshop. "And what," as Pepys would say, "shall be the end of it, God knows."

METER AND INSTRUMENT SECTION: CHAIRMAN'S ADDRESS

By R. S. J. Spilsbury, B.Sc.(Eng.), Member.

(*Address delivered* 4*th November*, 1932.)

In looking back on the activities of the past session we may, I think, feel satisfied that the progress of the Section has been maintained. During this period a satisfactory number of papers has been read; the subjects have ranged from the commercial measurement of power to the refinements of acoustic research; and the large attendances and active discussions at meetings have shown that the Section is, as it should be, representative of all classes of users of electrical meters and instruments. The membership figures are also very satisfactory, and in order to show their tendency I have plotted them

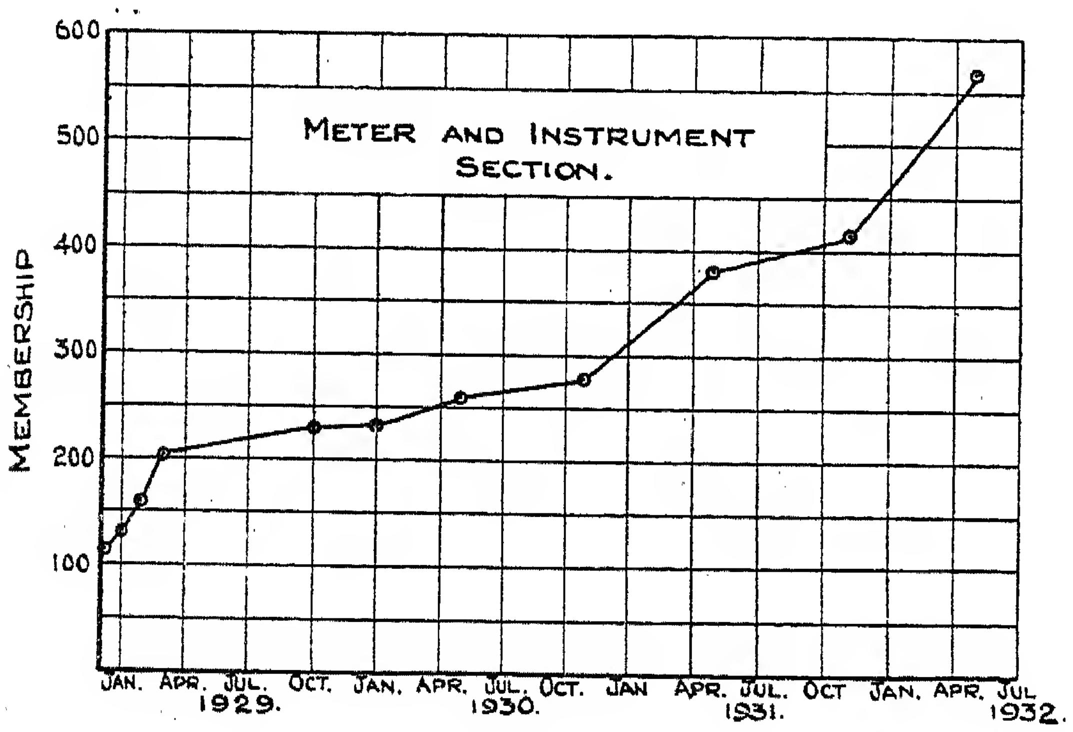


Fig. 1.

against a time base in Fig. 1. There is, as yet, no indication that our numbers are becoming asymptotic to a limiting value: on the contrary, the rate of increase during the second half of last session was the greatest since the first year of the Section's existence. I have to thank the members for the honour which they have done me in electing me to the Chairmanship of the Section.

I propose to give in this Address an outline of the equipment and methods which are employed at the National Physical Laboratory for the testing of alternating-current instruments for power frequencies. The majority of the methods with which I shall deal have already been described in the *Journal*; I shall therefore try to present them in much less detail, but in better perspective, as an account of the "state of the art" so far as the Electrotechnics Division of the Laboratory is concerned.

Buildings.

The space available for electrotechnical work consists of two bays, one 90 ft. × 25 ft., containing the generating machinery and one set of measuring apparatus, and the other 60 ft. × 25 ft., containing a duplicate set of instruments.

Power Supply.

The first requirement of the power supply for a laboratory in which indicating instruments have to be tested is steadiness: fluctuations in voltage and frequency waste an enormous amount of time and are very annoying to the testing staff. For this reason the whole of the a.c. power is generated by motor-driven alternators fed from large storage batteries. The largest set consists of two alternators, each rated very conservatively at 30 kVA, two motors, and a small auxiliary alternator used for frequency indication. To allow of variation of the relative phase of the voltages of the two main alternators, which is necessary when "fictitious loading" is used, the stator of one machine is arranged for rotation through an angle corresponding to about $1\frac{1}{2}$ pole-pitches: this adjustment is made by a small motor controlled from the instrument cabin. Particular attention has been paid to wave-form, and the results which are secured, even under difficult conditions, are very satisfactory. Fig. 2 shows a typical oscillogram: by way of contrast Fig. 3 shows the wave-form of another machine which is used when it is desired to examine the effect of wave distortion on an instrument. The two driving motors of the set are connected in series for low speeds and in parallel for high speeds: by this means a frequency range of 20 to 70 cycles per sec. is obtained, with good stability at all speeds. In order to secure steadiness of the field current,

four brushes in parallel work on each slip-ring. In addition the shaft of the machine was made hollow, so that leads could have been taken to mercury contacts outside the bearings if occasion had arisen. It is, however, found that with the slip-rings in proper condition, and the batteries steady, the generated voltage is constant within about $\pm$ 2 parts in 10 000 over periods of a minute or so. The capacities of the two batteries from which the set can be supplied are respectively 2 000 and 5 000 ampere-hours.

In addition to this set two others, having alternators rated at about 5 kVA, are installed. One of these has a frequency range of 20 to 110 cycles per sec., and is driven

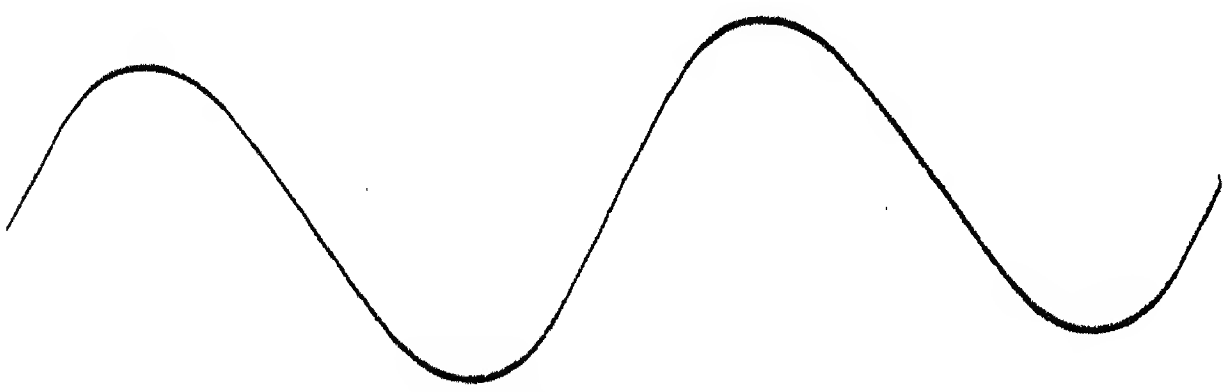


FIG. 2.—Normal wave-form.

by a special double-commutator motor: the other has a range of 40 to 60 cycles per sec., and is driven by a single motor of conventional design. This last set was installed recently, and reflects the standardization of frequency which the "grid" will secure.

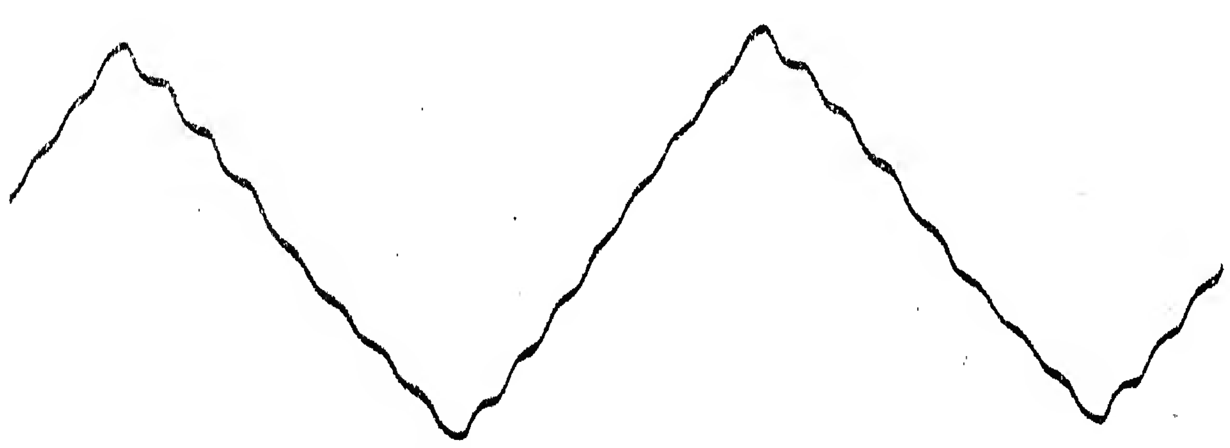


FIG. 3.—Special wave-form.

There are also various small sets for audio-frequency testing and similar special work.

CONTROL.

The voltage or current is controlled entirely by regulation of the field of the associated alternator, a rheostat embodying 3 or 4 dial-switches and a slide resistor being employed. Since variation of power factor is carried out by rotation of the stator of one alternator, the natural power factor of the circuit is of no importance: the regulation of the alternator field-current therefore provides the simplest method of control, and avoids the necessity for sliding contacts in heavy-current circuits.

All the rheostats are mounted on trolleys, and can be connected to permanent wiring in various positions in the test-bays. The power factor can also be controlled from these positions.

TRANSFORMATION.

In order to provide the necessary range of currents and voltages a considerable number of transformers is necessary, and as much of the test work is 3-phase the majority of these have been installed in sets of three. The largest bank employed for exciting voltage circuits consists of three 10-kVA units, each giving a single-phase voltage of 40 kV: other banks are rated at 4 kV and at 800 volts respectively. For current supply two banks having ratings of 4 000 and 200 amperes respectively are installed. The majority of these transformers are provided with series-parallel circuits on both primary and secondary sides, in order to give as much flexibility as possible. In most cases the continuous rating can be greatly exceeded for short-time tests.

MEASURING INSTRUMENTS.

The instruments used for test work are a reflecting electrostatic voltmeter and a reflecting quadrant electro-

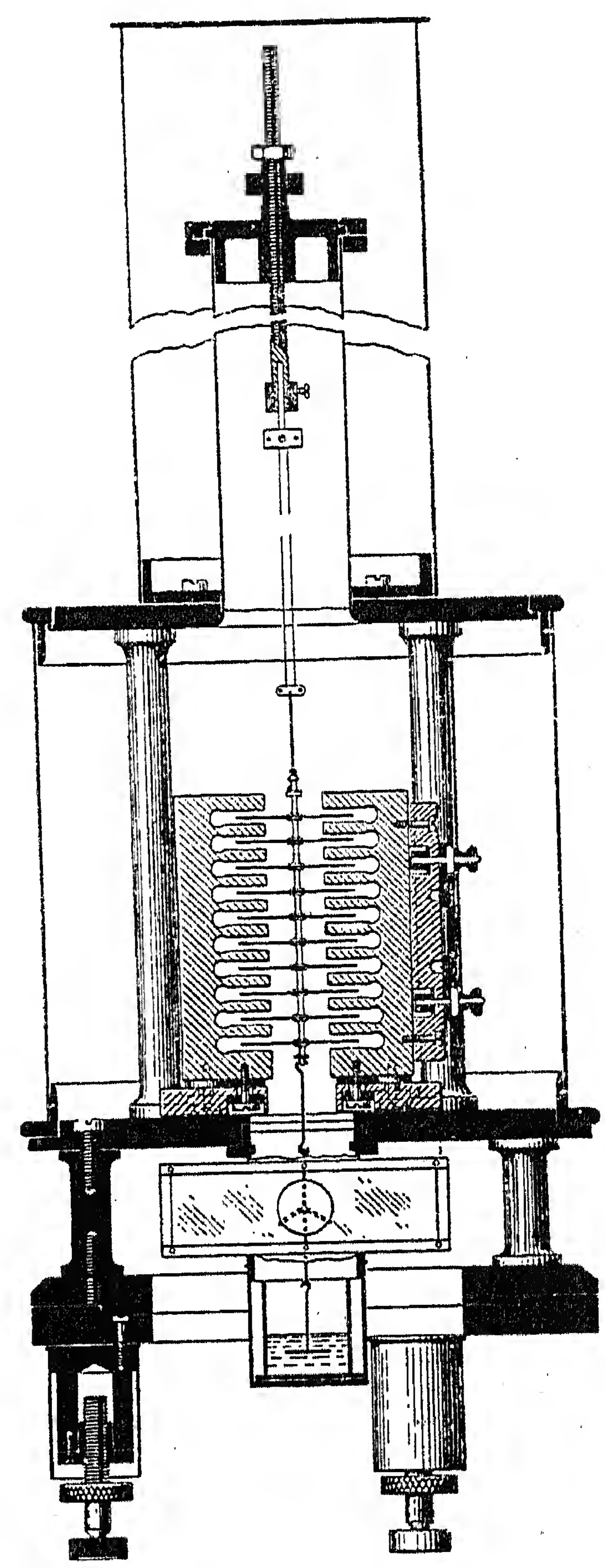


FIG. 4.—Electrostatic voltmeter.

meter, generally connected as a wattmeter. The electrostatic voltmeter, a sectional drawing of which is shown in Fig. 4, is a multicellular instrument, with the moving part so lightened that a bifilar suspension can be used. The weight of the moving system, including 10 needles with their separators, a large mirror, and a damping device, is 2·6 g. The instrument has a range of about 130 volts, and the scale length is about 700 cm: when voltage is suddenly applied the final reading is attained in about 15 sec. The sensitivity is about 1 part in 20 000 at the 100-volt point. The voltmeter is calibrated

on direct current by means of a special potentiometer: two readings are taken with voltages of opposite polarities applied to the instrument, and the mean correction is employed for a.c. work. The difference between the two readings, which is due to the contact difference of potential of the fixed and moving parts of the voltmeter, has been reduced to a few hundredths of a volt by suitable means. The calibration is readily made to an accuracy of 1 part in 10 000, since the instrument has no appreciable friction.

The quadrant electrometer has two sets of quadrants, supported from the base-plate by amberoid insulation: the gap in which the "needle" swings is about 2 mm wide. The needle is of aluminium alloy, 0·015 mm thick, strengthened by a rib near the edge. The production of these needles, which have to be very accurate in shape and perfectly flat, is a somewhat difficult operation. The comparatively low working forces of the electrometer do not allow a bifilar suspension to be used, but the single strip employed is satisfactory as regards fatigue. The instrument is damped by air friction only, and attains its final reading in about 20 sec. When it is used as a wattmeter a voltage up to 110 volts is applied to the needle, while up to 2 volts is applied across the quadrants: under these conditions deflections up to about 300 cm are obtained, and the larger values are readable to an accuracy of about 1 part in 5 000. The calibration of the instrument is performed on alternating current in order to avoid the effects of contact potential, which are not easy to allow for in a wattmeter. The method is to measure with the electrometer the power dissipated in a non-reactive resistor of known value, while the voltage applied to the resistor is simultaneously measured by the calibrated electrostatic voltmeter. The indication of the electrometer is compared with the true power, calculated from the resistance and voltage, and a correction deduced. The calibrating apparatus is so arranged that it indicates the true power directly in most cases. The instrument is independent of power factor, while any errors due to frequency, voltage, or temperature, are automatically included in the correction. The accuracy aimed at in measurements of current, voltage, and power, being normally 1 part in 1 000, it will be seen that the voltmeter and wattmeter have a considerable margin of sensitivity. This margin, in conjunction with the absence of any parallax errors, renders the deflections very easy to read.

The instruments are set up in a cabin with a curved wall, which carries the hand-drawn instrument scales. The calibrating and controlling devices for the instruments are arranged on a shelf below the scales, while the control rheostats for the alternator set occupy the floor. Special shielded leads connect the cabin with the racks on which instruments under test are mounted, and telephone communication—with a loud-speaker at the cabin end—is also provided.

Another piece of apparatus which is housed in the cabin is the stroboscope used for maintaining the alternator frequency at the desired value. This consists of a self-starting 3-phase synchronous motor, driving a translucent disc carrying a simple pattern. Behind the disc are mounted two special neon tubes; these are fed, through an induction coil, from an electrically-maintained tuning-fork, and give 3 000 flashes per minute. When the speed of the disc corresponds to frequencies of 25, 50, 75, or 100 cycles per sec., the pattern appears stationary. Since the voltages of the main alternators vary over a wide range according to the conditions of the test in progress, the stroboscope motor is not excited from either of them, but from a small auxiliary alternator coupled to the main set and having fixed excitation. This method of fixing the frequency has proved very convenient: the use of transmitted light gives an easily visible figure, while the torque of the motor is so high that there is normally no possibility of asynchronous running.

To enable the frequency of the tuning-fork to be easily checked the motor is provided with a contact-making device, driven through a 100 : 1 reduction gear and operating a Morse sounder. This enables the true frequency corresponding to a stationary stroboscope figure to be easily determined by timing the signals from the sounder.

Measurement of Voltage.

Voltages up to 130 volts are directly measured by the electrostatic voltmeter already described, or by a similar instrument modified to give full-scale deflection for 50 volts. For higher values, up to about 10 kV, the voltmeter is used in conjunction with unshielded resistance voltage-dividers. For still higher values a shielded resistance divider is employed.

The unshielded dividers, which originally had resistance elements of Duddell-Mather gauze, are now being rebuilt. Although the electrical characteristics of the gauze are good, it is somewhat costly and is also fragile and difficult to adjust or repair. It is therefore being replaced by thin, flat panels of insulating material, carrying a single layer of silk-covered wire: at the same time the resistance of the dividers is being lowered from 20 to 10 ohms per volt, in order to reduce the phase angle due to capacitance to earth, which is important when the divider is used in power measurement. Each divider contains 60 resistors, each of 1 000 ohms, and is rated for 6 000 volts: the resistance at this value is the same as that at zero voltage within about 1 part in 10 000, while the phase angle is rather less than 1 minute. Sixteen tappings are brought out to porcelain-insulated terminals, and enable a large number of division ratios to be obtained. The resistors are mounted on a whitewood frame, which is carried on a trolley having sprung wheels with rubber tyres. The divider used for higher voltages is of the Orlich type, in which the phase angle due to earth capacitance is eliminated by electrostatic shielding: the construction is indicated in Fig. 5. Each section of the resistor is enclosed in a perforated metal screen, and the potential of each screen is held at an appropriate value by connecting it to a point on an auxiliary divider. Each divider consists of 6 sections, and the apparatus is rated at 33 kV, at which voltage the resistance is within 1 part in 10 000 of the "cold" value: the apparatus is, however, usable up to 60 kV. The phase angle of any assembly of from 1 to 6 units is less than 1 minute.

Before leaving the subject of voltage dividers, I should

like to refer to the need for improved resistance materials. If the change of resistance due to self-heating is to be kept down to 1 part in 10 000, and the apparatus is to be reasonably compact, it is necessary that the temperature coefficient of the wire should not exceed about 3 parts in a million per degree Centigrade. Such material is at present difficult to obtain commercially, and is very expensive. The question is not an easy one, since composition, mechanical deformation, and heat treatment all affect the coefficient.

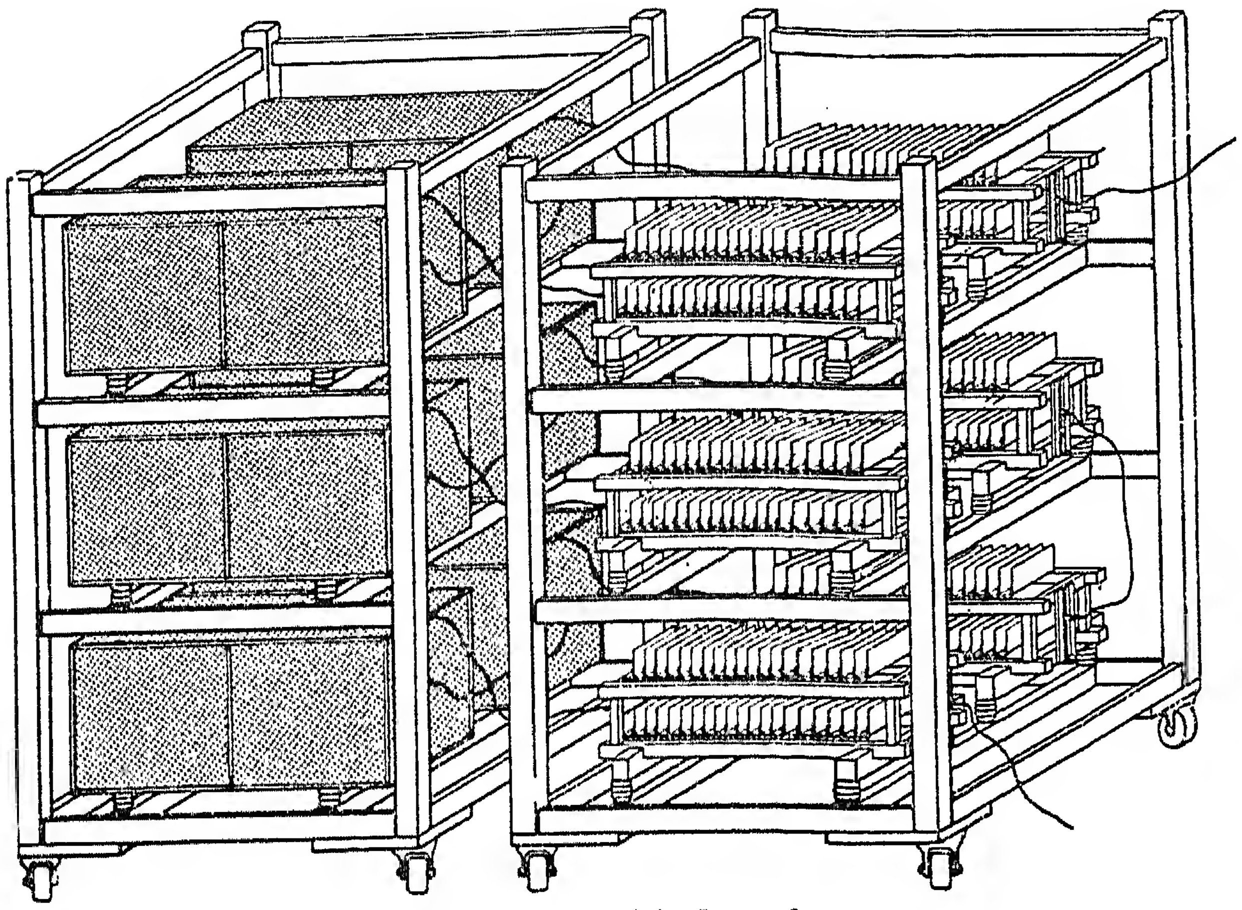


Fig. 5.—Shielded resistor.

Measurement of Current.

Since neither of the standard instruments will measure current directly, a voltage proportional to the current has first to be produced. For relatively low currents up to about 20 amperes this is most simply done by employing a resistor giving a voltage-drop of about 100 volts, a value which can be measured to a high order of accuracy by the electrostatic voltmeter. The design of such resistors presents no particular difficulty if good wire is available. This method is illustrated in Fig. 6(*a*). For higher currents a resistor for 100 volts would involve the dissipation of a prohibitive amount of power. The voltage drop is therefore reduced to 2 volts, and a special voltage transformer is used to step this voltage up to 100 volts, as shown in Fig. 6(*b*). The requirements for this voltage transformer are somewhat exacting; the magnetizing current must not be so high as to shunt the measuring resistor appreciably, and on the other hand the number of secondary turns must not be very great, since a high self-capacitance gives rise to a serious variation of ratio with frequency. The silicon-iron-cored transformer first used met the former of these conflicting requirements reasonably well, but the ratio variation was serious. Recently, however, a transformer with a mumetal core and a special tertiary winding has been obtained, the ratio of which, when loaded with the electrostatic voltmeter, is within 2 parts in 10 000 of its nominal value from 25 to 500 cycles per sec., from rated voltage to $\frac{1}{20}$ rated voltage.

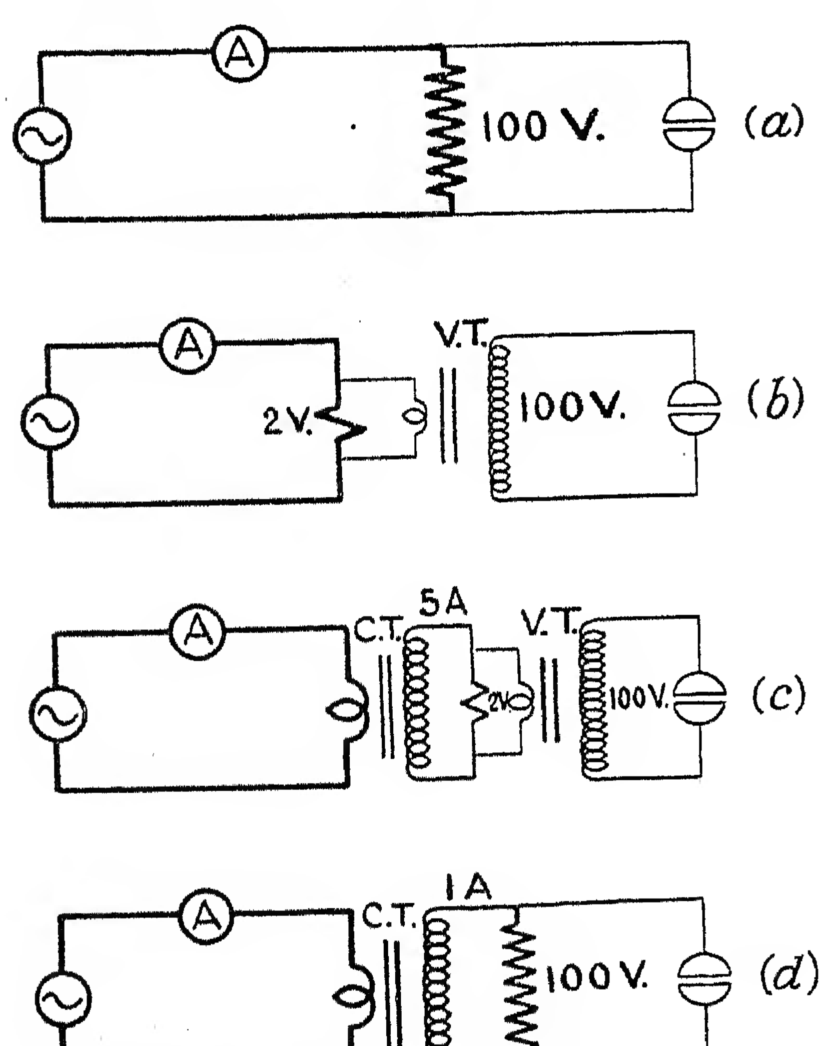


Fig. 6.—Measurement of current.

The resistors originally used in conjunction with the voltage transformer were of the Paterson-Rayner water-cooled tube type. Shortly after the introduction of mumetal, however, the possibility of replacing these by current transformers having small resistors connected in their secondary circuits was considered. Tests showed that such units had considerably lower phase angles and better stability than the tubes, but in the measurement of current, as opposed to power, they introduced a difficulty. Assuming that a current of 500 amperes had to be measured, the tube resistor employed would have had a value of 0·004 ohm, and the effect of the primary impedance of the voltage transformer shunted across this was entirely negligible. When, however, a transformer unit of the type shown in Fig. 6(*c*) was employed, the secondary resistor had a value of 0·4 ohm, and the shunting effect of the voltage transformer amounted to several parts in a thousand. This correction was quite definite and stable, but it conflicted with the practice which we endeavour to maintain of keeping the errors of auxiliary apparatus down to a few parts in 10 000. It was inconvenient to alter the values of the resistors because they are also used for other purposes.

The difficulty was finally overcome by a further recourse to mumetal. The properties of this alloy are so remarkable that it was found possible to obtain a 2 000/1-ampere current transformer which would supply a burden of 100 volt-amperes at 50 cycles per sec. without any variation of ratio greater than 1 part in 10 000 between full-load current and $\frac{1}{10}$ full-load current. This made it possible to connect a resistor dropping 100 volts directly to the current transformer, and so eliminate the voltage transformer altogether, as shown in Fig. 6(*d*). Since it is seldom necessary to measure currents above 2 000 amperes, the older method is still employed for them. Currents lower than 2 000 amperes can, of course, be dealt with by using more than one turn as the primary winding of the transformer.

Summarizing the above account, the devices used for current measurement are: for low currents, a resistor dropping 100 volts; for moderate currents, the special current transformer with a secondary resistor dropping 100 volts; and for high currents a current transformer with a secondary resistor dropping 2 volts in conjunction

with a special voltage transformer. The electrostatic voltmeter is, in all cases, the measuring instrument.

Measurement of Power.

The National Physical Laboratory has, I believe, the distinction of being the only standardizing institution which regularly uses a quadrant electrometer for wattmeter calibration. The instrument is used in conjunction with the voltage dividers and resistor or transformer units already described, a fact which will explain the stress which has been laid on the importance of small phase angles. The facility with which such auxiliaries can be interchanged makes the electrometer an extremely flexible measuring instrument. For example, one of the Laboratory instruments has been used to measure the power loss in a meter current coil, amounting to about 0·5 watt, and also to calibrate the instruments for a turbo-alternator test at about 40 000 kW—a range of 80 million to 1. With the plant at present available a test at 100 000 kW would present no difficulty, and work is in progress which should enable the limit to be set at a much higher value.

The circuit employed for a typical single-phase calibration is shown in Fig. 7. The needle of the electrometer is fed from a voltage divider connected across the primary winding of the voltage transformer forming part of the wattmeter equipment under test. The quadrants are connected to a resistor or a transformer unit which is in series with the instrument current-transformer. With the connections shown, the electrometer then measures the total fictitious power which the wattmeter under test should indicate. One of the electrostatic voltmeters, in parallel with the electrometer needle, monitors the test voltage continuously.

The electrometer is also used to set the power factor to the desired value. The voltage having been adjusted to its proper figure, the alternator phase control is varied until the electrometer deflection is a maximum, and the field of the alternator supplying the current is then varied until the deflection indicates that the volt-amperes have the correct value. The power-factor control is then operated, in a lagging or leading direction as may be required, until the deflection falls to the appropriate value calculated from the required power factor and volt-amperes.

For 3-phase measurements the "two-wattmeter" or "three-wattmeter" method is employed. Only a single electrometer is used, and it is changed over by means of the control switches in the instrument cabin. The fact that the instrument takes no appreciable current, and that no question of opening the secondary circuits of current transformers arises, makes this operation very easy.

Measurement of Energy.

The measurement of energy, the commodity which the supply industry has to sell, is of special importance. It is carried out at the Laboratory by means of the electrometer used as a wattmeter, in conjunction with suitable time-measuring devices. One such device is the ordinary stop-watch, reading to $\frac{1}{10}$ sec., which is cheap and compact, but has a somewhat limited life and appreciable starting and stopping errors. Another time-measuring instrument consists of a phonic motor, controlled by an electrically-maintained tuning-fork: by energizing small electromagnets, a train of counting wheels can be connected to and disconnected from the motor. This device reads to $\frac{1}{100}$ sec. or less, and although it well meets the requirements as to accuracy it is very bulky and costly, and the resetting mechanism for the dials gives a good deal of trouble. It is hoped that a compromise, consisting of a large watch which is started and stopped electrically, will be of assistance here.

In testing single-phase watt-hour meters the load and power factor are set as already described, and are held constant while a number of revolutions of the meter disc are timed. For polyphase meters the electrometer is connected to each phase alternately, and the readings obtained are averaged. Usually the meter is timed for about 120 sec., and three readings on each phase are

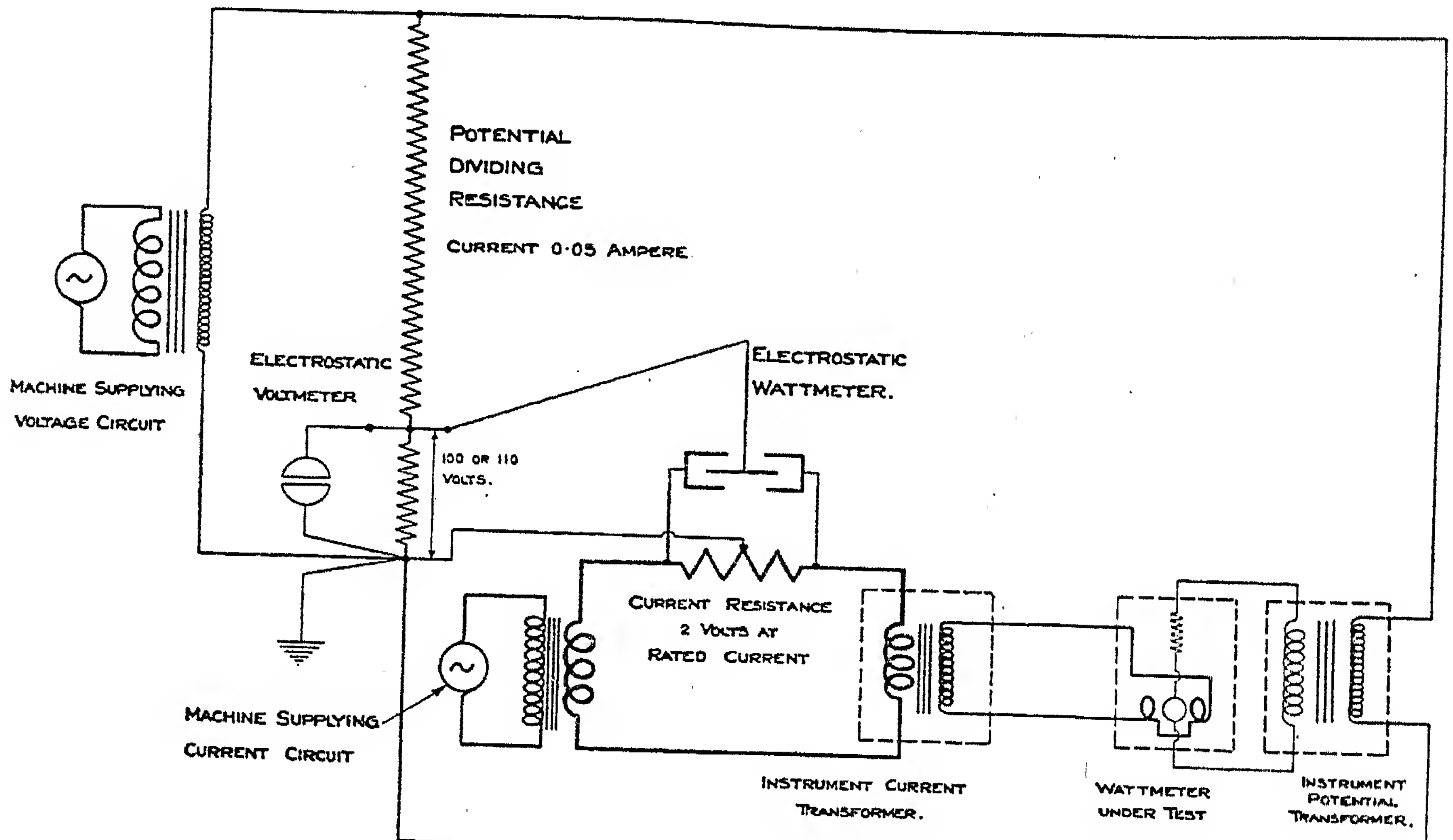


Fig. 7.—Verification of a commercial wattmeter with its current and potential transformers.

obtained during this period. Owing to the care taken to obtain steady voltages the energy passed through the meter is accurately given by the averages of these readings.

One of the difficulties of 3-phase work is the balancing of the heavy-current circuit. For instruments of theoretically correct design this is not of great importance, though reasonably well-balanced circuits are always used. For "balanced-load" instruments, however, if the test were made by conventional methods, the circuit might have to be balanced to an accuracy of a few parts in a thousand, a degree of perfection which cannot easily be secured or maintained. This difficulty is met by the artifice of connecting the measuring system in such a way that it is influenced by unbalancing in exactly the same way as is the meter under test. For example, in testing a balanced-load watt-hour meter of the type shown in Fig. 8, two measuring devices, shown

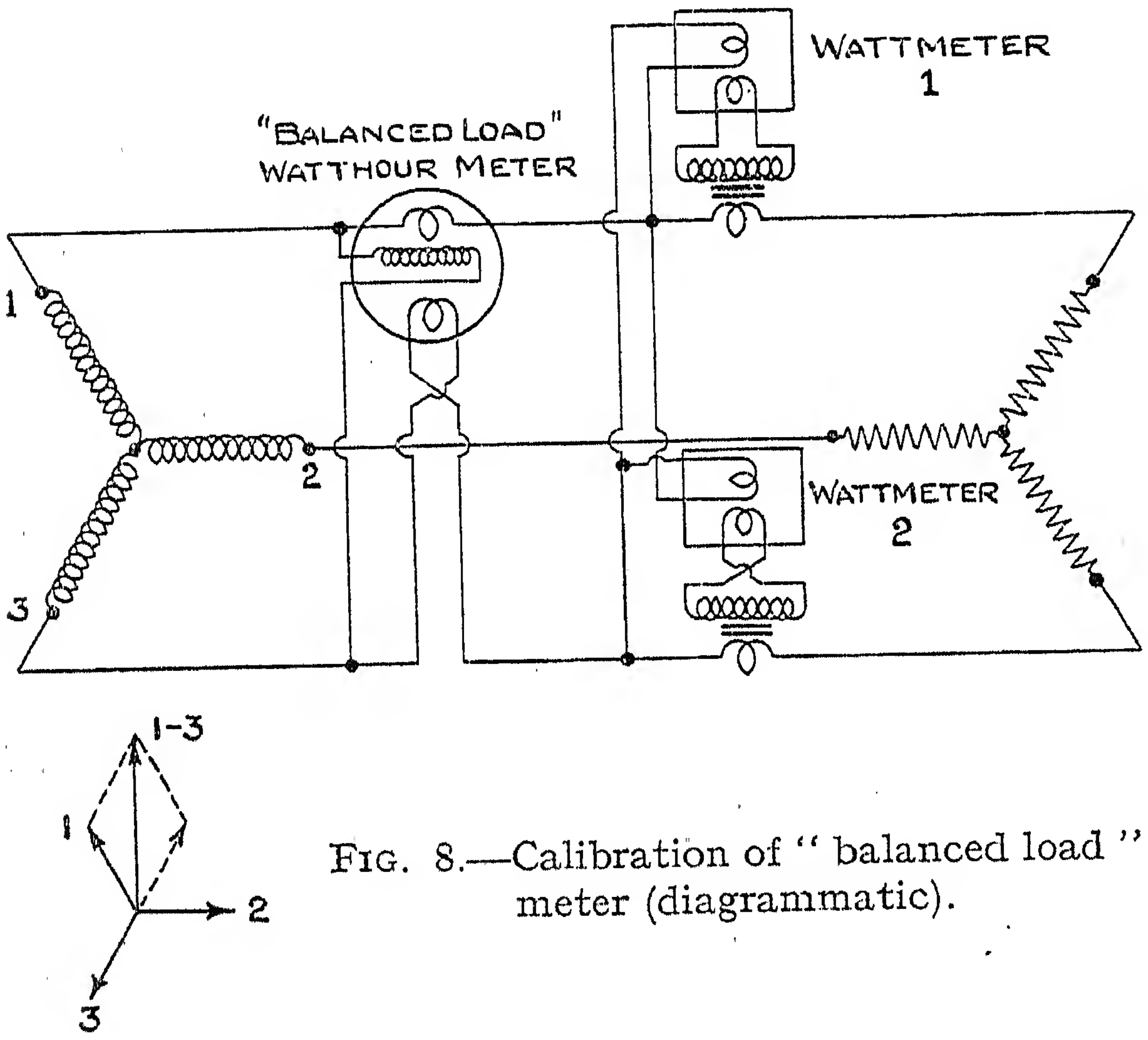


FIG. 8.—Calibration of "balanced load" meter (diagrammatic).

for simplicity as transformer-fed dynamometers, have their current coils energized from the same lines and with the same polarities as the two current coils of the meter, while both their voltage circuits are in parallel with the voltage circuit of the meter. As will be seen from the vector diagram, the sum of the wattmeter readings gives the 3-phase power when the circuit is balanced. If now unbalancing occurs, and causes the torque due to the lower current coil of the watt-hour meter to increase by x per cent, the reading of wattmeter 2 will also increase by x per cent, and the error deduced for the meter will be unaffected. Hence the calibration obtained is that which would be secured if the circuit were perfectly balanced. This method has been applied to the testing of a number of types of instruments based on theoretically unsound principles.

Current- and Voltage-Transformer Testing.

In the past the ratio and phase-angle errors of instrument transformers have been determined by electrometer methods, but latterly it has been thought desirable to relieve the pressure on this fundamental instrument by transferring the work to special equipments using bridge circuits. The bridges employed for both current and voltage transformers are very similar and are those developed by the Physikalisch Technische Reichsanstalt. I shall describe only the voltage-transformer equipment. The circuit is shown in Fig. 9. The principle of operation is the balancing of a part of the secondary voltage, derived from the small voltage-divider W, against part of the primary voltage derived from the resistor R in conjunction with the shielded voltage-divider H. The necessary phase adjustment is made by the variable mica condenser C, which is shunted across part of R. If the reversed secondary voltage of the transformer leads the primary voltage, the position of the condenser is that shown: if the angle is a lagging one the condenser shunts a part of R which includes the galvanometer tapping. Balance is effected by moving the galvanometer tapping along a slide-wire forming part of R, and also adjusting the value of C. The slide-wire scale indicates the ratio error directly, while the value of the resistance across which the condenser is shunted is so chosen that 1 μF is equivalent to 100 minutes at 50 cycles per sec. for either connection, so that the phase angle can also be read off directly. The sensitivity of

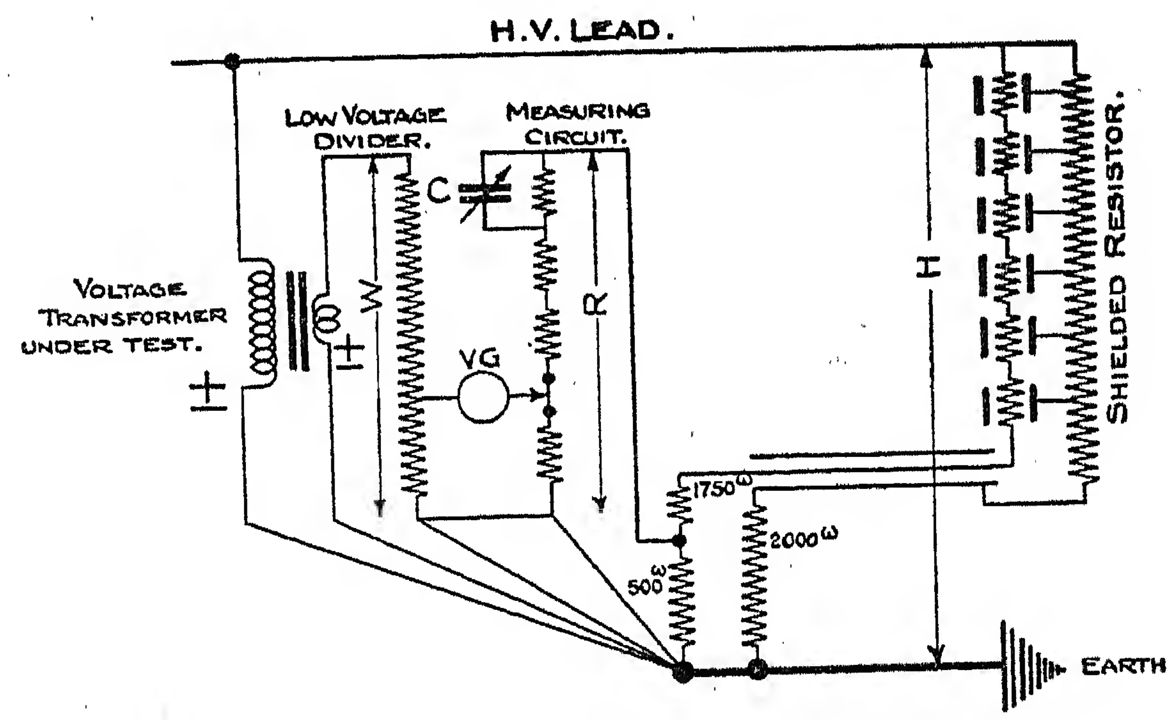


FIG. 9.—Voltage-transformer testing circuit.

the bridge used at the Laboratory is about 1 part in 20 000 for ratio and $\frac{1}{5}$ minute for phase angle, the respective accuracies probably being of the order of 2 parts in 10 000 and 1 minute. The apparatus is suitable for voltages up to the limit of the shielded divider: for values below 5 kV the unshielded dividers are used. The test table is arranged to be semi-portable, and is moved by a hydraulic lifting truck.

Miscellaneous Measurements.

In addition to instruments measuring the quantities already mentioned, various others such as frequency meters, power-factor indicators, reactive-kVA meters, etc., have to be calibrated. Frequency meters are usually checked by timing a number of revolutions of the alternator set, the stroboscope being inconvenient for calibration work. In testing certain special frequency indicators, however, an accuracy of about 1 part in 50 000 in the frequency determination is required: in such cases a synchronous motor is employed to drive a contact disc, and the signals from this device are compared with signals from one of the Shortt standard clocks, by the use of a large drum chronograph.

Power-factor meters are tested by means of the electrometer, the watts and volt-amperes in the circuit being determined in the way already outlined in connection with wattmeter testing. The definition adopted for power factor in 3-phase unbalanced circuits is that of Campos, as recommended by the British Standards Institution, but the balance is maintained at a figure such that all the suggested definitions give substantially the same result.

The calibration of meters for measuring reactive power is also carried out by means of the electrometer.

Standardization Methods.

As the fundamental requirement of a standardizing institution is accuracy, all measuring apparatus must be checked at intervals the length of which depends on the constancy of the unit in question, as shown by its previous history. The sub-standards used for this purpose are maintained by another department of the Laboratory, which has custody of certain fundamental standards.

The quadrant electrometer and the electrostatic voltmeter are checked at the working voltage and frequency before starting any new test, and at least once a day during the progress of the work. The whole equipment is provided in duplicate and, to guard against any drift in the calibrating apparatus, the two electrometers are compared at intervals of 2 months, at power factors of unity and zero, and the two voltmeters are also compared. At intervals of 6 months all current-measuring resistors, current transformers, and voltage dividers are calibrated. At intervals of 12 months the current transformer and voltage transformer testing-tables, all the calibrating apparatus for the electrostatic instruments, and the tuning-forks for the stroboscopes, are re-standardized. Many of the instruments carry labels on which the current errors are entered, for use in specially precise work.

In addition to this maintenance work, during every normal test a check is made by an independent method. When a watt-hour meter, for example, is being connected up, an independent set of current and voltage transformers is included in the circuit, and dynamometer wattmeters of the highest class, with 12-inch scales, are connected to these transformers. At least once during the progress of the test the indications of these dynamometers are compared with those of the electrostatic instruments, and concordance within about 2 parts in 1 000 has to be shown. The dynamometers and their transformers are included in the general standardization programme. Similar methods, involving standard transformers, are employed in tests of current and voltage transformers. This system entails a good deal of extra work, but the fact that none of the apparatus is common to the two systems of measurement invests the results obtained with a high degree of probability.

In concluding this account of electrotechnical work at the Laboratory, I might feel, if I were addressing another audience, that I ought to apologize for dwelling so long on mere routine measurement, with its insistence on parts in a thousand and parts in ten thousand, and without the glamour of pure research. Here I feel that I need not do so: in this Section at least we understand that the great structure of electrical science as we know it to-day rests on the foundation of measurement. It is the aim of the National Physical Laboratory to keep that foundation sound.

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MERSEY AND NORTH WALES (LIVERPOOL) CENTRE: CHAIRMAN'S ADDRESS

By A. Cecil Livesey, Member.

"SOME ASPECTS OF THE ELECTRICAL INDUSTRY IN RELATION TO GREAT BRITAIN'S ECONOMIC POSITION."

(*Address, abridged, delivered at* Liverpool, 17*th October*, 1932.)

Electrical Industry and Exports.

The times and conditions in which we have been living during the last two or three years are exceptional, and it is therefore perhaps appropriate that in choosing a subject for this Address I should endeavour to present to members of this Centre, situated as it is in a large industrial and shipping area, certain aspects of the electrical industry which in my opinion are not receiving sufficient prominence.

The welfare and prosperity of the workpeople, the professional classes, and, indeed, of the whole community of Great Britain, are to a large degree dependent upon the successful exportation of a substantial proportion of the products of this country. Explore, as we may, possible alternatives, the fact remains that we are, and probably always shall be, dependent upon our exports. This dependence upon exports is an important factor so far as the prosperity of the electrical engineering industry is concerned. Anticipating the revival of industry and commerce, I ask myself what the electrical industry is doing in regard to the important questions of research and development, manufacturing, and last, but by no means least, marketing and distribution, to improve its competitive efficiency and to enable us to maintain and to expand, in the face of present-day conditions, our trade in overseas markets.

Perhaps at this stage some of you are already saying to yourselves, "All this may be very interesting to manufacturers and traders, but I do not quite see what direct interest it has for us." I submit, however, that this matter is vital to all of us, whether we be manufacturers or power producers, traders or buyers, lecturers or research workers. It is inherent in the nature of conditions and progress to-day that the electrical industry, one of the comparatively new industries, should play a very important part in the prosperity of our country. This being the case, our own individual prosperity and even, in the final and logical issue, the very livelihood of each one of us is dependent upon the success of the electrical industry in the increasingly important contribution which it will make towards our national well-being. Ever since the period of Great Britain's industrial evolution, our engineers—civil, mechanical, and electrical—and our engineering manufacturers have always played a leading part in placing this country in the forefront. British machinery and British engineering skill have always ranked second to none. Consider the monuments erected in all parts of the world, to the skill and enterprise of our engineers and contractors; monuments in the shape of bridges and dams, railways, harbour works, and power-supply stations. In many cases the work involved was carried out in the face of extreme physical difficulties and under hazardous conditions. No matter in what part of the world we have carried out work and done business, we have always earned the respect and goodwill of our customers. This is a great heritage, and one which each succeeding generation must strive to supplement and extend. British engineers to-day are not inferior in skill and enterprise to those who won success in the past; we have the necessary technical ability; we have capable, skilled, and industrious workers; our manufacturers and manufacturing organizations are second to none; and our financial status and integrity rank high.

When we examine certain aspects of the electrical industry at home we cannot fail to be impressed by the steady expansion of the business of power supply. During this period of world-wide depression, when other important countries have shown a falling-off in electrical power generation, this country has shown a steady and continuous increase. This is very gratifying, and is in itself a healthy sign. As the limit of expansion in industrial, domestic, public-service, and various other fields, has by no means been reached, or even approached, a steady growth in this direction may be anticipated for many years to come. This, even in a time of industrial depression, is not without a beneficial influence in the electrical industry. It has enabled numbers of our manufacturers to maintain to a considerable degree their productive capacity, and consequently their efficiency. A thriving industry at home is an essential base from which to attack overseas markets. It is only in so far as it contributes towards this end, however, that I am concerned with this country's supply industry. Although certain countries export electricity in bulk as a commodity, we have not yet reached this stage, and therefore it does not come within the scope of this brief survey. Some economists have been accustomed to regard the consumption of electrical energy as one of the indicators by which to judge the economic progress or prosperity of a country. The experience of the last two or three years, however, has proved this practice to be misleading.

What then is our position, and what should be our policy? I have mentioned the competitive efficiency of the industry, and by this I mean the ability of the whole industry to compete in the world's markets. What can be done to strengthen the industry from this point of view? I have alluded to four of the more important

component factors in the structure of the industry, and will now refer to these four in greater detail.

Research and Development.

It will be obvious what I mean by research, but perhaps I should state that I mean by development the initial designing, making, testing, and proving, of a projected piece of apparatus or machinery. This stage usually follows, or is pursued concurrently with, research proper; it precedes the final designing and production stage, and might be called "practical research." Are we as an industry using our actual and potential resources in the direction of research to the best advantage? When we attempt to answer this question we are confronted with the fact that the strong individualism which is ingrained in the British character has in this connection a retarding influence. This individualism is a valuable asset in many directions, but it often carries a corresponding defect, that of inadaptability and reluctance to co-operate. How much stronger we should become if we could retain the keenness and will to accomplish which go with individualism, whilst securing the advantages of co-operation, and co-ordination of technical efforts!

We have an Electrical Research Association with a fine record of progress and usefulness. It has carried out researches and has published reports of great value, and of unquestioned authority, on a variety of problems. Those who have been in touch with the work of the Association, and have been ready to apply its findings to the solution of their own particular problems, must in many instances have been saved an immense amount of time and money. It has been established that the Association's researches into cables, insulating oils, and insulating materials, to mention but a few, have resulted in annual savings to the supply and manufacturing industries of well over a million sterling. The Association has made available, for the use of large and small concerns alike, data the cost of obtaining which would in many cases have been beyond the resources of all but a few firms and supply undertakings. Much of the work which has been done, however, has not yet been brought to practical fruition by manufacturers.

The valuable—one might well say, vital—work which the E.R.A. is doing, deserves to be more widely known. I fear that it is comparatively little appreciated outside the sphere of its contributory members and supporters. The Institution, recognizing the value of the vital work done by the E.R.A., contributes a large sum annually to the funds of the Association, and supports its work substantially in other ways. The results of various E.R.A. researches have often been the subject of papers read before the Institution and published in the *Journal*.

Measured by comparison with the productive capacity and resources of the electrical industry, however, the scope and the opportunity of the E.R.A. are comparatively limited, and it is my purpose to suggest how these may be widened to the ultimate benefit of the whole industry, which is really the object of the Association's existence. Research must always be carried on. Some investigations of simple character can be made by individuals and smaller undertakings; others of more complex character can only be dealt with by firms of substantial size and resources. How often must it be the case, however, that a given line of research is being pursued simultaneously by a dozen people in this country? How often does someone embark upon a line of research, complete data upon which are already available? Is this not wasteful and inefficient? While it is true that the E.R.A. does not exist for the purpose of carrying out researches into the special problems of the individual firm, it does conduct investigations which are of common interest.

In my opinion, it is in the interest of the industry at large that the Electrical Research Association should be much more widely supported, and that its sphere of usefulness should have the widest possible application. This would be possible if every section of the industry gave the Association its full backing. The amount of money spent annually upon research by manufacturers alone must be very considerable; if even a portion of this were pooled it could be utilized along more effective channels. A great deal still remains to be done, and a number of problems constantly await solution. Certain public supply authorities and other organizations such as the National Physical Laboratory and some of the universities have done sterling work in providing facilities for research and test, and a few of the large firms with fully-equipped laboratories of their own have greatly assisted the Association. These resources are not readily available, however, to the majority of manufacturers, and progress is greatly hampered in consequence. There are many who advocate, for instance, the provision of a central testing station in which the rupturing-capacity tests of circuit breakers (a matter of major importance to-day, for obvious reasons) could be adequately carried out. The E.R.A. have devoted much time and attention to increasing the rupturing capacity and reliability of circuit breakers, and it seems not unreasonable to suggest that the proposed test facilities should be placed entirely under their control. There is one such testing station, privately owned, in this country, but could not facilities in this direction be made available to all by the co-operation of everyone concerned? I think this could be done by and through the E.R.A. by a suitable extension of its organization and scope.

I do not subscribe to the objection that the extension of the activities and equipment of the Association in this and other directions would entail too great a cost. Such cost, based upon a constructive programme, could be estimated within reasonable limits beforehand, and it would not, if shared by the whole industry, represent more than a reasonable charge on any section or firm. On the other hand, who can measure the cost to the future of our industry of neglecting to take this step? I feel that this question of research will be much more important in the future, and that it must become one of the main corner stones, so to speak, in the structure of the industry. Some of our foreign competitors are well equipped and well organized in this respect, and it behoves us at least to reach the same standard, for only thus can we keep in the forefront of world progress. This country cannot be satisfied with a minor place.

Initial development is closely allied to research, and *is* research up to a point, but for my present purpose I prefer to regard it as having the separate though

complementary function laid down by the definition I have already given. The reason for this is that I would suggest an extension of the activities of the E.R.A. so as to provide facilities, including a properly-equipped workshop, for the making-up of experimental pieces of apparatus. Given these, there are surely many directions in which researches bearing on practical developments could be profitably pursued; for instance, switch contacts.

This matter of contacts is really an all-important one, to which even at this stage of progress too much attention cannot be given. Varying and opposing claims are made for this or that form of contact, for this or that purpose or application. Divergent opinions are held, for instance, as to the suitability of a given form of contact for a given purpose, not only by manufacturers but also by users' engineering staffs. In order to comply with the requirements of the latter, in some instances it is necessary that the manufacturer should employ two or more different designs, with a consequent increase in cost and a corresponding reduction in manufacturing efficiency. When the non-technical buyer goes into details of this kind he must be a little bewildered by the opposing claims for different types offered him by manufacturers. Would it not make for progress and efficiency generally if questions such as this were investigated and determined, and correct forms developed, by some independent central authority, whose findings and recommendations would not only be acceptable to, but also accepted by, manufacturer and user alike?

I should like to suggest another function which the Association might exercise with advantage to all concerned. It might carry out standardized type tests upon the products of any manufacturers who cared to submit them, and the results could be recorded and certificates issued. The latter would have a recognized status, and would be available to anyone, including competing manufacturers, on payment of a small fee. Such a service would be a means of providing for manufacturers a healthy stimulus towards improvement, and would give the purchaser a foundation of technical knowledge on which to base his decision as to the respective merits of different designs.

Before leaving the subject of the activities of the Association I would mention that its reports have been of great value to our industry in connection with international technical conferences. They have enabled British representatives at such conferences to take a leading part, and this in itself is bound to assist, indirectly, our export trade.

Manufacture.

The manufacturing side of the electrical industry has of recent years exhibited certain tendencies which have had the effect of weakening our general competitive efficiency. One of these tendencies is for more and more firms to embark upon the manufacture of an increasingly wide variety of machinery and apparatus, so that we now have a host of firms, most of them making more varieties than they can profitably sell. Even in times of full industrial activity few of these firms would have sufficient turnover or manufacturing capacity for any one type of apparatus to produce this type efficiently and economically. A number of firms pursued this policy of adding to their range at a time when the industrial market was already diminishing and when there were already too many people in the field, regardless of the fact that to do so was not in the interests of our industry as a whole, and was therefore detrimental to our interests as exporters.

I am not referring here to the domestic market, which, especially in such things as electric fires, is largely ruled by the tastes of the lay public, and also to some extent perhaps by changes of fashion. For this reason, and also because in Great Britain the domestic market is expanding, there is justification not only for a wide variety of types and designs calculated to appeal to all tastes but also for periodic changes in design. At the same time there is probably room for some measure of rational co-operation among manufacturers of this type of equipment.

It must surely be obvious that the present state of affairs in which our manufacturers are attempting to make too many kinds of apparatus, with insufficient production of each, cannot fail to impair our chances of supplying foreign markets. There is prevalent a notion that the increased competition brought about by this multiplicity of manufactures is a good thing, and that it benefits the purchaser. That this idea is a mistaken one can readily be demonstrated. Instead of a number of firms each making various pieces of apparatus already marketed by their competitors, it would surely be better for them to concentrate upon a limited number of lines, so that each firm would have sufficient production-quantities in their respective lines to enable them to manufacture efficiently and economically. If such a course of action could be secured by common agreement, substantial benefits would result. Redundant types and designs could be abandoned; considerable savings could be effected in the initial costs of designing, tooling up, and plant; and if the best features of the existing designs could be embodied in the fewer types which would then be made, a superior article would result. It must be self-evident that if a scheme such as this were adopted it would benefit both manufacturer and purchaser. It is the opinion of many thinking people that some fundamental change of this nature must be brought about before the manufacturing section of our industry can be placed upon such firm foundations as are essential if we are to strengthen our position both at home and abroad.

Here again, however, we shall encounter that strong individualism to which I have already referred, one of the manifestations of which is the excessive competition now ruling. We must all realize the drawbacks of this.

At one time intense competition between individual firms was regarded as essential to industrial efficiency and progress. However justifiable this may have been in the earlier days of our industrial evolution, and when we were practically the only substantial manufacturing country, such a point of view is no longer tenable. In competing for our share of world trade we have to meet, among our foreign rivals, the full strength of manufacturing and financial combines, and unless we put our house in order at home we shall be ill-equipped for this struggle. If the theory of the survival of the fittest were

to hold good in the realm of unrestricted commercial competition, the results would be disastrous. It might mean the survival of the financially fittest, but it would be more likely to bring our industry to the verge of ruin, through the lowering of profits to vanishing point on the one hand, and, on the other, the progressive lowering of the standard of quality which would inevitably follow. Such a calamity would have consequences for all of us which we would not care to contemplate, but we need not contemplate anything of the kind, because common sense will prevail.

I am not an alarmist, nor do I suggest any new remedy. I only advocate the application of some measure of that process of rationalization about which we have heard much in recent years, but without certain of its attendant disadvantages. I am sure it is not beyond the wit of our people to develop the means of securing this. Possibly it could be assisted by some form of financial interlinking, so devised as to preserve the separate entity of each firm, whilst at the same time realizing to the fullest degree the benefits which would ensue from wholehearted co-operation.

It would be very helpful if it were considered the duty of such purchasing bodies as Government departments and statutory undertakings to accept manufacturers' standard designs—having regard, of course, to the conditions to be met—instead of imposing special specifications, which sometimes unnecessarily increase the cost. At the same time, it must be acknowledged that much more is done nowadays in this direction than formerly.

Before leaving the subject of the manufacturing position, I should like to refer briefly to railway electrification and the important influence it may have upon this. Suppose, for the purpose of argument, that a programme of main-line electrification were to be proceeded with in the near future; what, for instance, would be the position of our electric-locomotive builders? Would they be prejudiced by the fact that the railway companies manufacture their own locomotives and other machinery? The strength of our export position in respect to such machinery depends entirely upon the activities of our private firms, and not upon those of the railway workshops, which cannot export. If these private firms have to admit that they do not manufacture for our home railways their foreign trade may be affected.

Marketing and Distribution.

The disposal of our goods in foreign markets is in these days a complex problem; many considerations have to be taken into account and many difficulties surmounted before any measure of success can be achieved. I propose to deal only with the basic factor of our marketing and distribution organization for export trading. Apart from the large firms who can carry their own branches in the important trading countries of the world, our industry generally is not organized to make this important side of our trading activities fully effective. This is not surprising, in view of the expenditure of effort and money entailed by unrestricted competition in the home market among our own manufacturers. The individualism and excessive competition to which I referred when speaking of manufacturing are very much in evidence in our selling organizations, so that we have a considerable number of agents and selling representatives competing for a limited amount of trade. At a first glance this condition of affairs may appear to be to the advantage of the purchaser, but this is really a fallacy. Reasonable competition is good for everyone, but excessive competition actually increases the selling cost, and therefore the selling price, and in the long run the purchaser pays. If this were not so, money would be steadily draining out of our industry, the ultimate result of which would be that parlous state to which I referred when speaking of the effect of such competition upon manufacturing.

So long as this state of affairs continues at home we shall be ill-equipped to meet modern conditions in world trade competition. Meet them we must, and we can only do so effectively by a unified and co-ordinated effort. A number of firms, jointly represented by an efficient marketing and distribution organization, could accomplish effectively what they could not individually afford to attempt. By this means new markets abroad could be opened to a considerably increased number of our manufacturers, and this would eventually be favourably reflected in our export trade, for such an organization as I have outlined would have sufficient strength and status to make it a formidable rival to the similar organizations of our foreign competitors. A co-operative scheme of this nature is being tried in South America by a number of British manufacturers, and it is to be hoped it will meet with sufficient success to encourage further efforts in this direction. I do think, however, that before we can hope for any solid success a changed outlook is necessary, and I believe this will eventually come about.

It must not be supposed that the problems with which I have dealt are the only ones which our industry has to face to-day. There are many others, but whereas many of these cannot be solved by the industry alone, we are able, if we have a mind to do so, and are convinced of the necessity, to take steps to overcome those difficulties which I have mentioned.

In conclusion, I would emphasize the need for cultivating a courageous outlook. Let us abolish, where it prevails, that condition of pessimism which would almost have us believe there is no great future for British industry. This pessimistic attitude of mind is dangerous, because it is insidious, and it is liable to have curious manifestations. On more than one occasion during recent months I have met people whose attitude seemed to be that no one has a right to be making any profit in industry with conditions as they are, and that anyone who tries to do so is to be looked at askance, as though guilty of an offence against his fellow men. Let us make away with harmful influences of this sort. Let the extent and severity of the present trade depression be the measure of our power of recovery. The electrical industry has become one of this country's greatest assets, and there lies in our hands in these difficult times something of the nature of a trust. Upon our fulfilment of this trust our future largely depends, and upon it our ability will be judged by future generations.

WESTERN CENTRE: CHAIRMAN'S ADDRESS

By F. H. Corson, Member.

(*Address, abridged, delivered at* Gloucester, 17*th October*, 1932.)

In considering the choice of a topic for this Address I have reflected that the Institution, representing a specialized branch of engineering, is already the parent of two highly specialized groups, the Meter and Instrument Section and the Wireless Section, and it would seem logical to expect further group formation as our knowledge grows, and as our work increases in complexity. This process of subdivision, which is at once the cause and the effect of rapid progress, gives rise to the danger that, in its ultimate development, the Institution may consist of numerous groups of experts, each tending to know "more and more about less and less." Even now, difficulty is often found in choosing, from the large number of papers presented, a few upon subjects which will be of interest to any considerable proportion of our members.

Following this line of thought, it would seem that a chairman's address may, with advantage, be broader in scope; and that instead of the detailed examination of some section of our activity, it may make a wider, if perhaps somewhat superficial, survey of the field of engineering science and practice.

Scientific discovery, implemented by engineering method, has made possible enormous improvements in the conditions of life. Bacteriological research has shown us that cleanliness is the key to the conquest of zymotic disease, and the schemes of the engineer for providing potable water and for removing sewage have been instrumental in reducing the virulence of many epidemic scourges, in completely stamping out some of them, and in considerably increasing the length and vigour of human and animal life. In this connection I would mention the work of Becquerel, Röntgen, and the Curies, which has given us X-rays and radiology in our hospitals and in our industries; the work of Otto, Diesel, and Clerk, which gave us the internal-combustion engine, and, through it, rapid land, water, and aerial transport; the work of Hertz, Lodge, Fleming, Marconi, and others, in the development of radio communication, which is still only in its early stages.

Yet in his recent presidential address to the British Association Sir Alfred Ewing said that the world is not worthy of the heritage of material wealth, the outcome of the work of scientists and engineers, upon which it has entered. This raises the question of the value of a gift when the recipient, for whatever reason, is incapable of using it. The opinion expressed by Ewing represents by no means an isolated personal view—H. G. Wells and many others have spoken in similar terms—and it is beyond question that the political and economic events of the past few years, and in particular of the last 12 months, have awakened doubt in many minds whether the great advance in scientific discovery and its application to the service of the community through engineering have been, on balance, of real and tangible value. It is suggested, on the contrary, that they have exerted a powerful influence directly stimulating many of the ills that have befallen us in these latter days. We have heard from authoritative sources that our civilization is on the verge of collapse, and many thinkers whose work cannot be described as unduly timorous have counselled a halt in the course of scientific research, lest the fantasy of "Frankenstein" and his monster should materialize in the fact of our inability to restrain the machinery we have created.

It has been a great part of our work to devise and perfect means of communication and transport in order to remove the impediments offered by time and space to the interchange of thought, of speech, and of commodities, among the nations. It is, in fact, mainly by the agency of these improvements that the peoples of the world have become materially interdependent to a degree disproportionate to their political development. The transmission of news of economic, financial, or other disturbance in one country, instantly to all the others, has precipitated reactions which under former conditions would have matured more slowly, if indeed they had occurred at all. World confidence and credit, the foundation of all international relationships, have thus sustained simultaneous widely-distributed shocks which their loosely-articulated political structure has been unable to withstand.

I have chosen this example—electrical communications—from many that might be given, because Sir Alfred Ewing has singled it out as one of the few gifts by engineering to humanity, that could be regarded as of unqualified beneficence. On the other hand, Sir Arthur Salter, in his book "Recovery," attributes no small share of responsibility for the world paralysis we are now experiencing to this very facility of communication, in that it has constituted a formidable weapon in the hands of the more sensational and less conscientious sections of the Press in all countries.

At times of depression and misgiving such as the present, it is, I think, especially desirable to reassure ourselves, if possible, of the usefulness of what we are doing, and to that end to check up our work against other standards of value than our own. While admitting that the calamities that do not happen arouse more anxiety than those which do, and that history is full of unfulfilled presages of disaster, we cannot, I think, deny that our present circumstances give some ground for alarm and gloomy foreboding. The present paradoxical position of scarcity of commodities, of diminution of comfort, and of difficulty in finding employment, in the midst of greater natural wealth than the world has ever

possessed, is a clear indication that the machinery of civilization is out of gear. The fact that we can see no better remedy for this than the actual destruction of coffee, cotton, grain, and rubber, the wealth we have created, and that we should deliberately renounce the use of our possessions in what we call measures of economy, are abundant testimony to the extent of the disorder.

Much has been written and said on the subject of the cause of the present crisis in world affairs, and many theories have been propounded for its alleviation. I do not propose to attempt to trace the causes of the crisis, much less to submit any suggestions for escape from it, except to say that in general our difficulties seem to arise out of our inability to adapt ourselves with sufficient readiness to the changing character of our environment, and that the work of engineers is closely concerned with these changes. In proportion as the present rate of change is likely in the future to increase or to diminish, so will the penalty of our failure to adapt ourselves to it be greater or less than it is now.

It may be of interest to try to make some estimate of the probabilities in this connection. I will first deal briefly with the two suggestions to which I have already referred, namely that we are on the verge of catastrophe and that we should restrain scientific research.

Sir Flinders Petrie, in his book "Revolutions in Civilization," analyses the various civilizations of which historical evidence is available and shows that in their general order of evolution they have all followed a substantially similar course. He shows that mankind has never been able to make continuous progress, that in learning and in the arts there have always been periods of advancement alternating with periods of stagnation and retrogression, and that material prosperity has constantly been subject to ebb and flow. Again, he shows that civilizations have not collapsed at their zenith but after a period of declining vigour which has, in most cases, prepared the way for military conquest by less highly cultivated races. If we search for evidences of degeneration and diminishing vitality we find that, amongst other achievements, we have learned in the last few years to cross the Atlantic in half a day and to bridge it by speech in a fraction of a second. Our improvements in transport are taking us more frequently and in greater numbers upon ever-extending journeys outside our own territories. We are becoming more sensible to, and appreciative of, other modes of life and thought than our own. We are spending an increasing amount of time, thought, and money, upon educating our perception of the wide difference between life and merely earning a livelihood. We are gaining ground daily in the conquest of illness and disease, and are learning how to make our lives longer in duration and fuller in their content. These and the scores of other examples which could be given are not indicative of waning energies, and if history can be relied upon as a guide there is some ground for reassurance against the fears which would stampede us towards ill-considered measures of reconstruction.

As to the suggested restraint of scientific research, Ewing and many others have pointed out that success in the conflict with natural forces has outrun progress in our relationships with our fellow men, and from this point of view some retardation of the progress of scientific research would, if it were practicable, be a reasonable method of re-establishing the correct relative position. A moment's reflection upon the connection between scientific discovery and the engineering work deriving from it, however, will show the impossibility of controlling the progress of research unless, indeed, we are prepared to forgo all attempt to improve our knowledge and our conditions of life.

How shall we put a value upon knowledge of the action of the cosmic rays that may be gleaned by Prof. Piccard's 10-mile balloon ascent, or by the observations of astronomers in America of the recent eclipse of the sun? What is the significance of the investigations of Dr. Cockcroft and Dr. Walton into the structure of the atom, and of their recent success in splitting up the atom of lithium? Shall we prohibit this type of research because at some future date it may reveal to us the secrets of atomic energy, and destroy our present elaborate and inefficient methods of generating power by the combustion of fuel?

The familiar example of Faraday's discovery of magnetic induction, which lay fallow for half a century and has since served as the foundation of the electrical industry, and the thermionic valve, the development of which could not be predicted, are two instances within our own purview. They could be multiplied almost indefinitely from those fields of research with which the Institution is not immediately concerned, and they show, I think, that our remedies must be sought in some other direction than that of the restraint of scientific research.

It would be manifestly impossible in the space of a single short address to sketch even in outline all the widely-scattered effects of engineering work upon the conditions of life. We must therefore follow our customary practice of obtaining from the examination of selected test pieces some indication of the character of the whole.

Some 20 years ago Alexander Siemens delivered an address* to the Institution of Civil Engineers in which he considered the contribution of engineering to the welfare of mankind and to the progress of civilization. He selected for comparison with our own times the classical period of Greek civilization some four to five hundred years before Christ, a comparison which shows that since then we have improved more conspicuously in our surroundings than in ourselves. Siemens's conclusion was that so far as engineering work is concerned the outstanding advantages of the present over former times are due mainly to improved communications and to the use of mechanical in place of manual power, both of them conspiring to reduce the cost of "obtainables." His analysis was concerned with material and not with moral values; the aspect of the matter suggested by Ewing and the others, which may be compared with giving detonating cartridges to ignorant workmen, was not considered. In his use of the word "obtainables" Siemens included not only the necessities but also the luxuries of life. As the luxuries of one age become the necessities of the next, and as

* *Proceedings of the Institution of Civil Engineers*, 1910, vol. 183, p. 4.

there seems to be no imaginable limit to the creation of new luxuries, I think that his selection will serve equally well to-day, and that a glance at our progress in communications and in the applications of mechanical power will convey a fairly reliable impression of the rate at which our conditions of life, dynamic and static, are changing.

I do not propose to spend time upon that aspect of communication which concerns the transmission and reception of electrical impulses, but rather to consider communication from the point of view of locomotion. In order to set the matter in its true perspective we must go back rather over 100 years, to the time when this question of improvement in transport was perhaps as vividly in the public mind as it is to-day. An article on "Canals and Railroads" which appeared in the *Quarterly Review* of March 1825 was mentioned by Mr. W. Grierson in his presidential address* to the Institution of Civil Engineers 3 years ago. He quoted this extract from it: "It is true that we who in this age are accustomed to roll along on hard and even roads at the rate of 8 or 9 miles an hour, can hardly imagine the inconvenience which beset our great-grandfathers when *they* had to undertake a journey, forcing their way through deep miry lanes, fording swollen rivers, obliged to halt for days together when the waters were out, and then crawling along at a pace of 2 or 3 miles an hour." It is clear, however, that even then there were not wanting those who refused to allow themselves to be carried away by the enthusiasms of the moment, for in the same journal we read: "We are not the advocates for visionary projects that interfere with useful establishments. We scout the idea of a general rail-road as altogether impracticable. . . . As to those persons who speculate on making railways general throughout the Kingdom and superseding all the canals, all the wagons, mail and stage coaches, postchaises, and, in short, every other mode of conveyance on land and water, we deem them and their visionary schemes unworthy of notice." I do not know with what authority these views were expressed, but it is interesting to note the very different attitude of Siemens† in 1910 when referring to the possibility of equipping balloons with sufficient mechanical power to make them travel in any desired direction independently of the wind. "We all know" he says, "that the feat has almost been accomplished but we do not know how far the art of flying will develop. Perhaps we shall soon be able to disport ourselves in the air in the marvellous way described by Lord Lytton in his book 'The Coming Race.'"

In glancing backward for a moment along the road we have travelled I have had in mind the sketching of a background against which our present attainments could be the more clearly seen, and also the fixing of two points some distance apart upon the curve of progress, by which some indication of its future course might perhaps be imagined.

Evolution manifests itself in the creation of new types as much as in the growth of those already existing, and the advance in transport has consisted more especially of recent years in the development of the newer methods at the expense, to some extent, of the older.

Rail transport would seem to have reached approximately its maximum economic speed, and to be tending to the improvement of the average rather than of the maximum. Thus the use of heavier locomotives and carriages, the construction of heavier permanent way, the employment of better materials having greater shock- and wear-resisting properties, and the centralization of management, appear to aim more at improved reliability and reduction of cost than at greater velocity of transport. The railway still carries by far the greater part of the merchandise of industrial communities, but it is at present difficult to see whether its inherent obligation to maintain its own road and regulate its own traffic will permit its survival against transport over the common highway. The recent Salter Report imposes far heavier taxation upon road transport than it has hitherto borne, and the adoption of the report would be likely to check in this country the transfer of traffic from rail to road.

Road transport has shown enormous developments, the rate of progress being almost uniform until arrested—or, perhaps, suspended—by the recent world depression in trade. At the date of the outbreak of war, some 300 000 motor vehicles were licensed to ply on our 177 000 miles of road, the gross cost of road maintenance being at the rate of about £100 per mile per year. Recently-published statistics show about 2 million licensed vehicles on a very slightly increased area of road surface, which now costs, however, 3 to 4 times as much for maintenance. These figures, which relate to our own country, are paralleled in other countries throughout the world, and our own Commission of Inquiry into Road and Rail Transport has counterparts in the inter-state commissions of America, and other similar organizations elsewhere.

It is impossible to make any useful comparisons in terms of speed, because this is limited in general by conditions of public safety unconnected with transport. In Italy, where certain express services are run over roads reserved exclusively for the purpose, speeds approaching that of express railed transport have already been reached. Indeed the wide margin between present-day commercial speeds and the comparatively ordinary speed of 100 m.p.h. over distances up to 500 miles attained by racing cars on the track suggests a progressive advance in road speeds as conditions permit.

While the bulk of road vehicles are of the passenger-carrying type, there are in use something like half a million heavy goods lorries capable of carrying loads of 10 to 12 tons and completing their journeys in much less time than is possible by rail.

The development of aerial flight has almost all occurred within the last 20 years, and it is perhaps not yet possible to estimate its tendencies. I have prepared a curve showing the yearly advance in speed and in the distance of uninterrupted flight. The fact that it continues still to maintain a reasonably straight-line form suggests that, while there must obviously be limits in both these directions, they are not in sight. Mr. C. M. Poulsen, the technical editor of *Flight*, tells me that the world's distance record is a 5 000-mile flight from New York to

* *Proceedings of the Institution of Civil Engineers*, 1929, vol. 229, p. 3.
† *Loc. cit.*

Istamboul by Boardman and Polando, the seaplane speed record is held by Stainforth with a speed of 407 m.p.h., and the aeroplane speed record is that of Doolittle—296 m.p.h. As a further indication of what has already been accomplished I will quote some figures recently given in this city by the Master of Sempill. In 1919 the air transport of the whole world amounted to 1 million miles of flight over a route mileage of 3 000, while in 1931 83 million miles were flown over a route mileage of 185 000. In this country alone, commercial aircraft carried 25 000 passengers in 1931 and only 870 in 1919, while freight amounted to 653 tons carried 1 million miles in 1931 as compared with only 30 tons carried one-tenth of this distance in 1919.

Let us turn now to the second criterion—the utilization of mechanical power. It is possible, of course, to compare the figures obtained from the Census of Production for different years and by subtraction to arrive at the increase of power capacity. As an example, I would mention a recent quotation by Sir Josiah Stamp from the "Statistical Abstracts" of the United States, showing that between 1904 and 1925 the average amount of mechanical power used per worker in industry increased by 64 per cent, and that the quantity of industrial output per worker increased in an identical proportion. Such data are available in respect of Canada, the United States, Japan, and six or seven European countries, but the value of the comparison is destroyed by the great difference in efficiency between old and new types of power application. The effective yield of the rated horse-power of a modern electric motor is very much greater than that of an old-type steam or gas engine, and this difference is not taken into account in the figures of the Census of Production.

It is within the daily experience of those of us whose work is concerned with the use of power in industry that its effective influence upon production is determined rather by the intimacy and directness of its application than by a mere increase in its quantity. It is, in fact, common knowledge that where power can be applied directly to the machinery of production a very great reduction in the quantity of power required is usually obtainable, and from this point of view the mere comparison of quantities of power used in industry is meaningless. There can be no doubt that in 1925 power was more efficiently applied than 1904, and that in the case quoted by Sir Josiah Stamp the difference in effective power was considerably greater than is indicated by the comparative figures of installed capacity.

We see, then, that our examination of the two aspects selected as an index of engineering progress reveals no evidence of tendency to decline, but suggests that scientific discovery and its application to our daily affairs may, on the contrary, gain momentum, and bring with them ever-growing disturbance of methods of thought and work based upon earlier conditions of life.

The work of the engineer is defined in the charter of the Institution of Civil Engineers as "the art of directing the great sources of power in Nature for the use and convenience of man." It deals with the inanimate things of nature rather than with organized beings, but it may be argued that its purpose is inadequately met if we are content with the provision of the specific, and omit to concern ourselves with the conditions necessary for its beneficial use. Our mastery of the great sources of power in nature has already brought us within sight of such a plenitude of the kindly fruits of the earth as may serve, if intelligently used, for the needs of its whole population. That we are very far from such a consummation is evident in the constant appearance of the mirage of over-production, suggestive of a reality, which, as someone has said, cannot truly exist until the last Hottentot possesses a motor-car.

Established customs and national traditions are deeply rooted throughout the world, and great sacrifices must be made in order to remove the social and international jealousies and misunderstanding arising out of them. Prof. Miles Walker contended, at the York meeting of the British Association, that the habit of mind to which the engineer is trained, with its readiness to weigh the worth of new discovery and to relinquish the guidance of tradition where experience shows this to be wrong, may qualify him especially to deal with the much greater problems that are now before us. I would say in conclusion, that whether this be true or not, these larger matters must have our consideration if the work of the engineer is to come to the fulness of its promise, and the use and convenience of man are to be effectively served.

NORTH-WESTERN CENTRE: CHAIRMAN'S ADDRESS

By G. F. SILLS, Member.

"NEW APPLICATIONS, AND THE EXPANSION OF RECENT USES OF ELECTRICITY."

(*Address, abridged, delivered at* MANCHESTER *18th October*, 1932.)

A recent article in a technical journal was headed "Keep Abreast of your Profession." Most of us are, unfortunately, limited in our opportunities of being aware—at least in any detail—of many achievements which have recently been carried out. There are so many things about which one could obtain knowledge if one had more time. The average electrical engineer, however, has to devote his attention to one section only of electrical engineering.

It is probably correct to say that a new application of electricity usually leads to still further uses in other fields. It is only of comparatively recent years that wonderful strides have been made in these arts and sciences which particularly affect us. It has even been said that science and engineering knowledge are proceeding too rapidly. Materially, engineering in the last few decades has achieved marvellous things, such as transportation, telephones, telegraphs, the cinema, the camera—all of which have linked up the world in a way which could never before have been imagined. Is the world benefiting in the way it should? Has there been a proper adjustment of human ideas to fit in with these closer relationships? Are we drugging ourselves with pride in the merely material aspect of our achievements, and neglecting their potentialities in other ways?

Modern man has accepted all the benefits of science. These have been showered upon him in such abundance that he has ceased to wonder, and no new marvel is of more than a few moments' interest to him.

Part of the development of electricity consists in its explanation to the potential user. It is often said that we live in an age of electricity. At the same time, most of the members of the Institution depend upon it for their livelihood. It is unfortunate that even to-day many people are afraid of electricity, and this attitude is not confined to any one class. Here is a further field for the Electrical Development Association.

Electricity has developed so rapidly that people have not really grown up to be thoroughly used to it, and the dispelling of this mental darkness is of vital necessity both to us and to those we serve. A great opportunity lies before us to bring about the more effective understanding which is so much to be desired. All this points to the fact that a study of human nature should be included in our education, so that the technical man should appreciate the difficulties experienced by the non-technically minded.

Coming to the question of new applications of electricity, I propose to mention a few of the more recent ones and also other interesting developments. Time will not permit, however, of my making a comprehensive survey. I shall not confine my remarks to this country, as the interchange of engineering data is nationally invaluable if each country is to benefit.

It does not follow that, because in certain cases only a small amount of energy is used, those developments should not be treated with respect. One has to remember that if they are of great convenience and benefit in their different ways, they will undoubtedly help people to think electrically.

The use of the control grid in rectifiers is probably the most important development which is taking place in electrical engineering at the present time. This gives to the mercury-arc rectifier characteristics which are almost similar to those of the thermionic valve with three electrodes, where the third electrode is used for control purposes. The control-grid principle is somewhat similar to that of the third electrode in the wireless valve. In the case of the mercury-arc or mercury-vapour rectifier, however, it is not possible to achieve such complete control as with the thermionic valve, because the presence of the mercury vapour permits of considerable space charges, which tend to neutralize the action of the grids. The latter do, however, allow of quick interruption of current and enable the rectifier to act as its own circuit breaker, and they interrupt the output in an extremely short time, thereby doing away with the need for a high-speed circuit breaker.

A grid is placed in front of each anode and a connection is brought from this grid to terminals outside the rectifier. With the aid of suitable apparatus it is then possible to give the grid a definite potential relative to the cathode. The potential of the cathode is always slightly negative relative to the anode, and if the grid is made more negative than the cathode the arc cannot persist.

When the rectifier is operating, the potential of the grid is determined by its position in the arc, and it is only when the anode is not in operation that a voltage can be impressed upon it. For the interruption of current the potentials of all the grids are instantaneously made negative relative to the cathode by the operation of a small relay, which in turn is actuated by the line current of the d.c. side. When this is accomplished, any anode which is passing current continues in operation until the end of its normal half-cycle, but the next anode in the sequence will not function. The power required to charge the grids varies between 20 and 40 watts, and the current is interrupted in a period of time which varies between 15 and 20 milliseconds, the

actual time being dependent upon the point on the wave at which the relay operates. This characteristic of the rectifier which, as already explained, consists of setting the time at which the arc will ignite, enables many new features to be developed. It should be understood, of course, that the transformer winding connected to any anode is only in circuit with the external load during the time the arc is burning, so that any portion of the half-wave of voltage can be utilized.

If the ignition is delayed until the voltage has passed beyond its peak and is decreasing, the anode is operating when the transformer voltage is lower than its maximum, hence the d.c. voltage at the cathode is reduced. This enables the rectifier voltage to be regulated from the full value set by the transformer to almost zero. On the lower values of voltage the wave-form on the d.c. side becomes very irregular, but can be smoothed out by a suitable circuit. This opens up the way to compounding the rectifier, by utilizing the main current delivered on the d.c. side so that it operates the apparatus which energizes the grid, and causes ignition of the arc at such a time as will give the required d.c. voltage.

Various methods of energizing the grid have been developed, the simplest being a contact-making device rotated by a small synchronous motor. This contact device makes only one grid positive at any instant and leaves all the other anode grids with a negative bias, which may be supplied from a small metal rectifier.

An alternative scheme makes use of a sine-wave voltage for charging the grids in conjunction with a d.c. biasing voltage, the phase angle of the a.c. voltage being displaced relative to the anode by a small induction regulator.

It is impossible to enumerate all the possible developments, but the following are the principal ones which are under consideration at the present time:—

(1) Voltage regulation from a low value upwards, also voltage adjustment and compounding.

(2) A rectifier is enabled to protect itself and its transformer from damage by overload due to backfires or short-circuits.

(3) A rectifier can be made to generate an a.c. voltage at any frequency when fed by direct current, or by alternating current at some other frequency.

(4) A rectifier can be built to change the frequency in one unit.

(5) It is possible to allow the return of energy through the rectifier and thus permit regeneration of traction and other loads.

(6) A rectifier can provide a reversible link between a d.c. and an a.c. system. It is thus possible to use a battery as a stand-by for an a.c. load.

(7) Rectifiers can be used to replace Ward-Leonard sets for reversing rolling-mills and winder drives.

(8) To control d.c. motors on rolling stock, even when the trolley voltage is alternating.

(9) To feed single-phase railways from a 3-phase system at a different frequency.

(10) To regulate the wattless kVA on a high-tension a.c. system.

The grid-controlled rectifier is not yet fully on the market, though one or two rectifiers are running on experimental loads. A 20 000-volt rectifier with automatic grid control has been tested. This was supplying a dead load and could be short-circuited without damage, the rectifier picking up the load immediately the short-circuit was removed. Rectifiers of this kind can now be made for d.c. voltages up to about 30 000 volts, and investigations show that this figure can be raised to 50 000 volts. With the development of a similar rectifier running inverted, the transmission of power by high-tension direct current is becoming more practicable.

The sectionalized rectifier has now come into use. A 3 000-kW unit has been built in four sections instead of one. Each section is capable of operating independently of the others, or all sections can be operated in parallel, so that if trouble arises in one section the remaining three sections can still function, a further advantage being a gain in efficiency of 1 per cent. In physical size there is a gain in space, as the smaller units can be placed one on top of the other.

Control grids can be applied to glass-bulb rectifiers as well as to the steel-tank type, and it then becomes possible to use the smaller units for quite a number of purposes, such as relays, and for all kinds of regulating devices.

It is general knowledge that any ripples set up in the d.c. circuit can definitely be eliminated by a suitable smoothing circuit consisting of resonant shunts, and it has been established both here and abroad that the ripples have no effect whatever on either the commutation or heating of traction and other d.c. motors.

An important method of obtaining improvements in design is the accurate measurement of the performance of finished apparatus, from which further improvements can be carried out. A meter has now been made for assessing the noise of a machine, and another is a sound analyser. Another useful instrument is the precision "turns tester" to provide a quick and accurate test of the number of turns in a coil, the accuracy being such as to record an error of one turn in 3 000.

The accurate recording of time electrically is proceeding very rapidly, but it will probably mean some little argument with the supply authorities, as they may not like being told that their supply stopped at, say, 26 seconds after 2.35 a.m. The public seems to expect electricity to be perfect, which is really a compliment, for they are satisfied if there are nine ordinary clocks in the house some of which they forget to wind and none of which keeps correct time. I was recently looking through a new house and was intrigued to see that over the centre of every mantelpiece a plug had been fixed for connecting an electric clock.

The synchronous motor may be used to overcome the difficulty of synchronizing the receiver with the transmitter in television sets. This avoids the superimposing of synchronizing signals on the picture signals, with a consequent improvement in definition. Such motors also would have plenty of power available.

Gas-filled relays have now been developed for counting rapidly passing objects up to 1 000 events per second.

Photo-electric relays as now produced for industrial purposes have many novel applications, such as the checking and counting of gift coupons in machines, including the stopping of the machine automatically as soon as the supply of coupons is exhausted.

Electrically lighted advertisements and other devices are now photo-electrically controlled; in fact the uses of such relays are legion and there will be astonishing developments.

A smoke detector for power stations is now available, the principle being that a beam of light is projected across the smoke duct and measured by a light-sensitive cell. Then by potentiometer measurement of the cell voltage, an indicator can be operated which shows the smoke density. Lighthouses can be put into operation by a photo-electric relay.

A portable photo-electric photometer has been designed for measuring the amount of light falling on any surface. This type of instrument should prove extremely useful to illuminating engineers in obtaining data on street lighting, as it will measure values as low as 0·002 foot-candle.

Voltage regulation is being given much more attention, and it is interesting to record that in all the main distributing transformer substations on the large Manchester system, arrangements are being made to control the supply automatically within certain defined limits.

Many people are probably not aware that electricity is now being developed from water power in Great Britain on quite an appreciable scale, large developments having taken place in Scotland, and it may come as a surprise to most of the members to learn that by the end of 1934 there will be no less than 333 000 h.p. of water power being developed, 275 000 h.p. of which is in Scotland. These plants are of a comparatively large size, and I have left out of account the numerous small plants in operation.

It will probably be a greater surprise to hear that in the near future some of the power in question will be exported—if one may use the term—from Scotland to supply the northern part of Lancashire at night.

The ultimate capacity of the undertakings in connection with the principal Scottish water-power schemes alone will enable 390 000 h.p. to be developed. The creation of the grid has, of course, had a great deal to do with the recent hydro-electric developments in Scotland, and such schemes as the Grampians and Galloways owe their existence to it. When trade revives and the load on the grid increases, it is safe to assume that the further 115 000 h.p. which can be developed in Scotland will be utilized.

If we include Ireland the total horse-power which can economically be developed is no less than 749 000 h.p., which is not bad for the United Kingdom, a country which is not supposed to possess any water power.

It is a decided advantage to have in this country a variety of large water-power plants so that foreign buyers can realize not only that such equipment is made completely in this country, but also that we have actual operating experience.

Outdoor substations seem to be rapidly coming into greater use. Carrying this a stage further, outdoor substations have been constructed involving the use of large totally-enclosed machines of both the horizontal and the vertical types.

In certain cases abroad, most of the buildings housing the generators have been dispensed with.

In the case of vertical water-wheel generators, which are quite common, the roof is low, and from the gantry crane above—which is out in the weather—access to the generators is through a round cover or hatch above each machine. For ordinary repairs the rotor can be lifted far enough to clear the stator without opening the whole machine to the sky. In the middle of the big cover is a small hole just sufficient to admit the crane hook.

In the United States outdoor hydrogen-cooled synchronous condensers have been used. The largest is of 50 000 kVA and looks like a Lancashire boiler without steam connections. The advantages claimed are the reduction in size, less noise, lower operating temperatures, decreased windage losses, increased efficiency, and saving in installation cost. Large vertical-shaft synchronous condensers of many thousands of kVA have been adapted for placing out-of-doors, using cooling air direct from the surrounding outside atmosphere.

It has been shown on paper that hydrogen cooling would be an economic proposition for large steam turbo sets of 40 000 kW and upwards.

A minor, though rather interesting, development, especially for outdoor work, is the insertion of the potential and current transformers in the top of the main transformer tank, the meters, etc., being placed in a metal box nearby.

132-kV oil-filled cable has now been in satisfactory service abroad, and is also working in this country; and the knowledge and experience gained on oil-filled cables have demonstrated that 220-kV cables can operate with the same factor of safety as 132-kV cables without exceeding practical dimensions.

The development of the condenser type of joint with complete control of the distribution of stress makes it possible to design a safe joint for 220 kV. Sixteen miles of this 220-kV cable has actually been manufactured for use on the Continent. It has been found that 132-kV oil-filled cables can be used with the same insulation thickness as the standard 33-kV cables of the ordinary type. The reservoirs and feeding tanks for these very high-voltage cables have, as a result of experience, been reduced to one-third of their original bulk, and one oil system only is necessary to serve three phases for the 3-core cable.

In connection with oil switches and switchgear, arc control has now been put on a much more scientific basis, and it has now arrived at a stage which justifies the assertion that revolutionary changes in theory and in technique have taken place. Circuit interruption does not concern switches and circuit breakers only; it includes every element of the electric circuit that contributes, accidentally or intentionally, to the stopping of an electric current by interposing an obstacle to its continued flow.

It is only recently that there has been any really scientific attempt to deal with the arc problem. The accepted ways have always been to lengthen the arc, cool it, etc. At the present rate of development it looks as if in the near future all new circuit breakers, including the air-break type down to small sizes, will be materially improved by the adoption of a real method of arc control.

Metal-clad switchgear has more than firmly established

itself. In fact there is now 132 000-volt metal-clad gear of $2\frac{1}{2}$ million-kVA rupturing capacity, using oil-filled cables for busbars and interconnections. One wonders, however, how oil-filled cables, when used in this manner, will stand up to short-circuits of the above order.

Oil switches for operation at 160 000 volts have now been made and sent out from this country; and it can be recorded that a 3 million-kVA rupturing capacity circuit breaker has been put into service on a 220 000-volt system, the circuit breaker being equipped with contacts giving scientific arc control.

Miniature control-boards are coming into favour in this country and, owing to their economy in space, are particularly suitable for large systems.

A complete control and metering board for a 200 000-kW station comprising five generators, five transformers, and four outgoing transmission lines with all attendant switching and synchronizing facilities, totalling 94 controllers, can be placed in a space 12 ft. long by 3 ft. 6 in. wide.

It is interesting to note that, in at least one of the large highly industrialized countries, fuses show signs of disappearing in favour of small automatic circuit breakers. Even in this country a beginning has been made with small circuit breakers in place of fuses. This small circuit breaker would be a boon to ultra non-technical householders, who are often frightened to replace a fuse.

Although distribution transformers have a high impulse strength compared with their normal voltage ratings, they are apt to flash over in service, even when protected by arrestors.

A number of tests have given fairly good proof that on a single-phase 3-wire distribution system the inter-connection of the earth lead of the primary arrestor with the neutral of the transformer secondary limits the voltage across the transformer insulation to that permitted by the arrestor alone, and introduces no additional hazard on the low-voltage circuit where the secondary neutral earth-resistance is low. With such a connection the voltage between the transformer windings under impulse conditions will not exceed the potential allowed by the arrestor. This potential is low enough practically to eliminate transformer failures from bushing flash-overs.

High voltage has been used in the past for dust deposition. To-day this use has been developed, and machines generating 40 000 volts have recently been made in this country and put into service for this purpose. I believe it to be the first time that dynamos have been used for generating this voltage.

The successful application of the regenerative principle to tramway equipments should, if energetically taken up, prolong the fight between tramways and omnibuses. As the fuel-oil omnibus, with its untaxed fuel, is developed, it will become a more serious competitor of trams and trolley omnibuses than is the petrol omnibus using taxed fuel. Incidentally, a matter outside all understanding is why two omnibuses owned by the same undertaking and on the same route, but one using petrol and the other fuel oil, should be treated so differently. A petrol omnibus pays 8d. per gallon tax, but when the extra mileage obtained per gallon with oil fuel is taken into consideration the tax paid on petrol for the same distance is 1s. 2d., whereas the fuel-oil omnibus, using imported fuel, pays no tax.

It is commonly assumed that the design of tramway trucks has made no progress whatever. This is not the case, as there has recently been put into service a number of flexible-drive tramway bogie-trucks with the object of a reduction of noise, easy riding, low loading, less wear on truck, and reduced maintenance.

It would be a matter of grave concern to the electrical industry if electric traction were superseded, and anything which is a definite improvement is therefore of great importance. The total unsprung weight of a double-deck tramcar mounted on two bogies of this type represents only 7·5 per cent of the total weight. As all four axles are driving axles, the whole weight of the car is available for adhesion; the maximum acceleration can therefore be obtained. There is really no truck, in the usual sense of the word, inasmuch as the motor frame itself with its gear casings supports the weight of the tramcar body and ties the two axles together.

Apparatus has now been devised for the electrical operation of railway level-crossings. Various safety factors have been taken into account in designing the apparatus. Bridges operated electrically are not new, but quite recently bridges have been built for semi-automatic operation, so that a skilled personnel is unnecessary. For railway bridges this point is of considerable importance, since wrong operation may be attended by disastrous consequences.

The first large rolling mill in this country has just been put into service in which both the main roll motors, each of 2 000 h.p., d.c., individually drive one main roll. This is a decided advance, as by this means the heavy pinions and pinion housings, with the attendant losses, are omitted, and there is also the absence of the slipping of the rolls relative to the surface of the metal. Each roll automatically assumes the rate of rotation corresponding to the speed of the surface of the metal in contact with it. The saving in mechanical maintenance is considerable, and the interesting electrical feature is the speed-matching of the two large motors, as these must run at identical speeds.

The electromagnetic preheating of rolls in steel-works is a very practical contribution towards overcoming the troubles of expensive roll breakages and loss of time, as the men can then commence commercial rolling immediately on starting up; an induction-type heater is used for this purpose, obviating expansion stresses, which start cracks and so damage an expensive roll.

Individually-driven live-roller gear, as distinct from the main rolls, is now coming into use in this country, although it has been adopted abroad for some time. The old way is for the rollers to be geared together in groups to reversing motors. A preferable method is to have the motors mounted on the live-roller spindles, so eliminating bevel and spur gearing and controlling the motors individually or in groups. Motors can be placed inside the rolls or mounted externally to the rolls; the latter is perhaps the best method, as the motor design is not tied to certain dimensions and, furthermore, replacements can more easily be made, all parts being fully accessible.

Both furnaces and industrial heating have been progressively developed and are now being given still greater consideration by users. In an artificial atmosphere, made by thermal dissociation of ammonia gas, it is now possible to obtain perfectly clean, bright, annealed, cold-rolled strip.

Heat-treatment furnaces of the double-deck type up to 28 ft. in length have recently been constructed for hardening and tempering the rear axles of cars, the top chamber being used for hardening and the lower for tempering. The use of electricity enables a temperature difference of 220 degrees C. to be maintained between the two sides of the furnace, so as to keep the end of the wheel sufficiently soft for screwing.

A furnace 115 ft. long has recently been installed for baking the decoration on pottery, the ware being placed on trolleys and introduced at each end of a double-tunnel kiln so that the outgoing material heats the incoming.

It is probably news to most of us that an adaptation of the electric furnace is now being incorporated in boiling-pots for the manufacture of plaster. In view of the fact that the power consumption is 240 kW per boiling-pot, this is decidedly acceptable to the power-supply industry.

Successful experiments have shown the possibilities of utilizing electricity for the withering and drying of tea, and a power scheme has already been worked out for a district with electric tea-drying particularly in view. A new electrical tea-dryer with safeguards against overheating has been put on the market. The proposed erection of a large hydro-electric station to supply power for this purpose shows the importance of the scheme.

The Electricity Commission of Victoria (Australia) have made practical investigations relative to the application of electricity to the curing of locally-grown tobacco leaf, and the results have been sufficiently encouraging to justify their continuance for a further curing season. This new application leads to the more economical distribution of the power now being transmitted in that area. It was ascertained that the electrical method of curing tobacco was technically sound. The time taken by the electrically heated and controlled kilns was about five days, as against seven days with the usual wood-heated type, and the loss of quality due to "sponging back" was eliminated.

Advances have been made in connection with telephones and telegraphs, and voice-frequency signalling. If alternating currents at different frequencies are applied singly or in any combination to a pair of wires, it is possible at the distant end, by means of filters, to separate the alternating currents of different frequencies from each other. In this way it is possible to obtain as many as 18 channels of communication over a single pair of wires. The alternating currents may be provided either by oscillating valves, or by small alternators run from a common shaft. It will be appreciated that combination voice-frequency operated channels and telegraph-switching will probably have an important future.

A recent development of automatic telephone exchanges is an arrangement whereby the connecting mechanism searches for a calling line, instead of there being a switching arrangement on each subscriber's circuit which searches for a connecting mechanism. The advantage of the recent change is purely an economic one, since it enables a smaller quantity of apparatus to perform adequately the switching functions of the exchange.

When visiting an automatic telephone exchange one of the most remarkable devices to my mind is the routiner which picks up the various sets of apparatus in turn and subjects them one after the other to a series of tests. The progress of the tests is indicated by the lighting of lamps, and the apparatus is left to perform its own functions. Immediately a particular piece of apparatus fails to pass the tests imposed the routiner testing-apparatus stops and calls attention to the fact that a defect has been found, also indicating its location.

Arrangements have recently been perfected by means of which subscribers renting teleprinter circuits will be able to get into communication with each other in a manner similar to that of a telephone exchange, and in this way messages can be transmitted with the utmost expedition. An interesting feature of the arrangement is a key marked "Who are you?" The depression of this key causes the transmission from the distant instrument of its exchange and number, so that there cannot be any possible doubt as to the office with which communication has been established.

In general, all main-line circuits will be worked by teleprinter, and minor circuits by telephone.

In connection with sub-audio telegraphy, a single telephone circuit can be used for both a telegraph and a telephone channel by installing filters and confining the telegraph signalling to a frequency of 100 cycles per second. This is, of course, filtered out from the telephone speech channel.

A useful advance has been that whereby conferences have been arranged in which the various members of a committee have been interconnected by transmitters and loud-speakers, so as to avoid the necessity of bringing all the people together. This is particularly valuable when a conference is required at exceedingly short notice and the people concerned are separated by long distances.

During the past year an increasing interest has been shown in the very short wireless waves below the range used for long-distance communication. These ultra-short waves open up new possibilities in the fields of television, directional wireless free from fading, electro-medical work, and certain physical researches. To meet such requirements new types of valves have been developed and an investigation of special circuits has been carried out. For wavelengths down to about 1 metre a magnetron valve has been developed which has proved much more efficient than the normal triode. Similar valves have been used successfully in a short-distance wireless telephone circuit operating on wavelengths below 1 metre, and recent investigations have enabled an output of $1\frac{1}{2}$ watts to be obtained from a single valve at wavelengths of the order of 20 cm.

Important strides have been made in providing greater safety of aeroplanes, and what are termed obstruction

lights have been designed for marking obstacles along airways and near air ports. There is one type which is suitable for application to high-tension transmission lines or to any other source from which high-voltage current is obtainable. Power is tapped from the high-voltage source by a string of suspension-type capacitors referred to later. There is also a type embodying a connection to low-tension lines.

The obstruction light gives a large splash of red colour, approximately 3 ft. in diameter, and is easily distinguished from other ground lights. It consists of U-shaped neon tubes and, although the tubes are connected in series, each is capable of operating alone and is automatically cut out if it becomes defective.

Small supplies of power up to 3 kW may be obtained from high-tension lines tapped directly by means of a capacitor potentiometer device. This consists of a number of suspension-type capacitors connected in series. These units look very like suspension-type insulators, and their construction is such that the capacitor will flash over the outside of the porcelain before it will flash through the inside. The characteristics are similar to those of line insulators. They can be suspended from an existing tower or a pole, and it is probable that they will be provided with disconnecting switches. As this type of equipment may be suspended, it is unnecessary to provide an enclosing fence.

Experiments have shown that it is feasible to read consumers' watt-hour meters by means of telephone lines, the connection being made through the power company's connection with the telephone exchange and thence to the consumer's residence by his telephone connection. The watt-hour meter has to be equipped for remote reading. The plan necessitates each consumer being a telephone subscriber.

It is suggested that the time is not far distant when electrical conditioning of the breathing air for offices and homes will become an actual fact. Our air will be supplied to us, year in and year out, at constant temperature and humidity, cleaned of mechanical dirt and germs and filled with exactly the right proportion of oxygen to keep us strung up to our maximum efficiency. We should certainly benefit from this, particularly in this part of the world.

Considerable use is now being made of the fact that the electrical conductivity of solids, liquids, and gases, varies with slight changes in their composition. This enables electricity to be used in quite a large number of manufacturing processes to control these processes automatically, for instance, by measuring the variation of acidity of a liquid.

With a view to preventing gas explosions, an arrangement has now been devised which will indicate the presence of a dangerous amount of coal gas. A hot platinum wire is placed in a position where the detection of the condition is desired. The gas burns around the wire and heats it still further. This small platinum wire forms one arm of a Wheatstone bridge, and is exposed to the gas in a small enclosure. The balancing arm of the Wheatstone bridge is kept at a constant temperature in air. So long as the conditions are safe the bridge is balanced, but immediately an unsafe condition arises a sensitive relay in the Wheatstone bridge arrangement closes the alarm circuit; this also may be utilized to switch on a fan which will clear the dangerous area.

In surgery, a needle supplied with high-frequency current is used for cutting; it also seals small blood vessels. By its use, operations are now carried out more quickly and safely than formerly.

SCOTTISH CENTRE: CHAIRMAN'S ADDRESS

By D. H. Bishop, Member.

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Introduction.

The rapidity of development in electrical science, both pure and applied, since the time of Faraday, has been greatly influenced by the comparative ease with which exact electrical measurements can be made. It is therefore not to be wondered at that for all kinds of measurements efforts are made to correlate with some electrical quantity the quantities to be measured. Even the monthly outputs of electricity by public undertakings are regularly used as indices of business and trade activity. Electrical methods are almost essential when occurrences take place in short periods of time; when the forces to be dealt with are small; and when it is necessary that the measurements should be continuous, especially if they have to be indicated at a distance.

Measurement of the Concentration of Solutions.

The first application of electrical methods which I have chosen to discuss depends on the variation of conductivity of a dilute solution of an electrolyte with the concentration of the dissolved salt. A particular example is the utilization of this characteristic to keep a continuous record of the purity or otherwise of the condensate as delivered from the surface condenser of a steam turbine. Those engineers who are engaged in the operation and maintenance of boiler plant in generating stations where sea water is used for condensing purposes know only too well the cumulative troubles that arise from almost imperceptible leakages of sea water into the feed water. The importance of having a warning immediately such leakage commences is intensified under modern conditions of higher boiler pressures and higher furnace temperatures. Now if the condensers are absolutely free from leaks (this is a difficult state to obtain and maintain) and if the boilers are not priming, the electrical conductivity of the cold condensate is very low. It rises rapidly with the addition of small traces of sea water; these may be far smaller than could be indicated, much less measured, by the ordinary chemical tests carried out by steam engineers. By keeping a watch, therefore, on the relative electrical conductivity by means of some kind of voltmeter, without anything more than a rough calibration at two or three points on the scale, it is quite easy to ascertain when leakage commences and whether it is increasing or remaining constant. The one difficulty is that the conductivity is also affected by the temperature of the water. However, conditions in a power station are repeated fairly closely from day to day, and it is not difficult, if the condensate is tested immediately it leaves the condenser and before it enters any of the heaters, to make corrections for temperature which are sufficient for practical purposes. One or two very useful commercial instruments have been developed for the purpose of these tests. The value of having continuous indications is very great, and whereas continuity can generally be obtained simply by electrical means it can only be provided with great difficulty by any other method.

Many years ago, when the steam-turbine generating station at Dundee was first put into operation and sea water began to be used for cooling purposes, it was intended to keep the feed water perfectly free from contamination with the circulating water. With this purpose in view, samples of the condensate were drawn off for chemical analysis during the small hours every morning at times when the load was light, because it seemed reasonable to suppose that leakage would depend on the difference of pressure between the circulating water and the steam in the condenser, and as this was practically constant the presence of salt would be most conspicuous when the volume of condensate was least. The chemical tests of these samples indicated that salt was almost entirely absent, and it was therefore very disconcerting to find after a few weeks that stalactites of sodium chloride were beginning to form on the joints of the boiler manhole doors. After much experimenting, during the course of which a conductivity indicator was extemporized, it was found that the amount of leakage increased with the load on the turbine, being zero at very light loads. This entirely unexpected result was finally traced to vibration of the condenser tubes caused by the steam flowing past them, just as the " singing " of telegraph wires is caused by the wind. When the load fell and the mass-velocity of the steam became less, the tubes ceased to vibrate and the packing at the ends of the tubes became tight again. When the condensers are free from leaks, special chemical tests indicate less than 7 parts of salt in 100 million parts of condensate.

There are many possible applications of this principle of conductivity indication in industries where it is important to keep the concentration of dilute solutions constant, or to have warning when changes of this sort occur, e.g. in water-softening processes. The method has limitations, however, especially when more than one salt is in solution.

Measurement of Moisture Content of Wood.

Another application of conductivity measurement is to determine the moisture content of wood, i.e. its state of seasoning. When a tree is felled and sawn up, the timber gradually dries and finally reaches a state in which it is deemed to be seasoned. This does not mean

that the wood has lost all its moisture, but merely that it has reached a state in which the quantity of moisture retained is dependent on the humidity conditions of the surrounding air. If the temperature and humidity of the air are altered, the moisture content of the wood will tend to alter to a value at which equilibrium is re-established. As wood dries, its strength increases and it becomes more immune from fungus attacks, but, in general, the point of greatest practical importance is that changes in moisture content are accompanied by roughly proportional changes in the cross-section.

Swelling or shrinkage of wood are matters of only too common observation. From expensive furniture down to the comparatively simple doors, windows, and floors of domestic architecture, we find examples of this effect. The fact that a board of oak or Scotch pine 12 in. wide may shrink $\frac{3}{64}$ in. in width in consequence of a loss of moisture content of only 1 per cent explains why more and more attention is being given to the subject of testing and controlling the dryness of timber before manufacture, with due regard to the purpose for which the finished article is required and the atmospheric conditions under which it is to work. These factors are recognized in most specifications of wood, which is required to be "well seasoned," or to have been "stacked" for a given number of weeks or months "under cover." Such requirements have no definite meaning, because wood termed "well seasoned" for one purpose may be unsuitable for another, and the drying which takes place in stacks will depend on the kind of weather, amount of ventilation, and other variables. What is really required in order to minimize the shrinkage or swelling is that prior to manufacture the wood should have been dried to a moisture content which is approximately the mean value it will attain when the manufactured article is in its final surroundings. Thus, suppose the moisture content of a piece of furniture varies from, say, 14 per cent at one period of the year to 10 per cent at another, there will be an unavoidable change in dimensions of say, 4 units; but if at the time of manufacture the wood contained, say, 16 per cent of moisture, there will be an additional change of 2 units, making 6 in all. If, however, the wood was dried to 12 per cent, the change in dimensions will only be $\pm$ 2 units.

The Forest Products Research Board of the Department of Scientific and Industrial Research have carried out some experiments on the daily and seasonal variation of moisture contents of wood samples, to represent furniture kept in different environments such as centrally-heated rooms, offices, warmed living-rooms, unheated rooms such as bedrooms, and also in protected situations out of doors in different parts of the country, and they have found that while the moisture contents ranged from approximately 9 per cent to 20 per cent and over, yet seasonal variations might be as low as 3 per cent. The results also showed that timber air-seasoned out of doors without further treatment is not dry enough for use indoors where shrinkage is of importance. For such products as cabinet work, decorative panelling, boot lasts, shuttles, and many others, it is becoming more and more important to specify and be able to measure the moisture content of the timber to be used. The standard method of measuring the moisture content is to weigh a representative sample, dry it in an oven at a temperature of 95° to 105° C., and weigh again in the usual manner. This naturally takes some hours to do, however, and it is not easily carried out in the field.

It has been found that there is an important relation between the direct-current resistance of wood and the moisture content, when the latter is below the fibre saturation point. Hassellblatt found that for birch, below the fibre saturation point (at about 30 per cent moisture content) the logarithm of the electrical resistance is approximately proportional to the moisture content, while for values above saturation point the resistance is only slightly dependent upon moisture content. Stamm, who carried out further work on the subject, found that practically all the other factors, such as density of the specimen, species of wood, direction of current flow with reference to the grain, and variation in the extent of the specimen beyond the electrodes, are relatively unimportant and may be neglected in comparison with the enormous effect of moisture. On the whole, for wood with a uniform distribution of moisture below fibre saturation point, the resistance can be related to the moisture content to the exclusion of other factors. For example, the resistance of a certain sample with 7 per cent moisture content was 25 000 megohms, with 10 per cent moisture 630 megohms, and with 15 per cent moisture 19 megohms, the resistance being measured between pin electrodes.

It is obvious, therefore, that comparatively rough measurements of resistance would give relatively accurate determinations of moisture content. An instrument has been developed for enabling the moisture content of wood to be measured by a non-technical wood-worker. The instrument contains a 2-electrode neon tube, evacuated and then filled with neon at a pressure of a few millimetres of mercury. The most important characteristic of this tube is that if a d.c. voltage is applied to its terminals, no current will flow until a certain definite voltage is reached. Current then flows with a glow discharge, and the current increases linearly with the voltage. If the voltage is reduced, the current is also reduced, but it continues to flow until the voltage is decreased to some definite value below the breakdown voltage. The current then suddenly drops to zero. The neon tube is shunted by a condenser, and the combination is fed through a resistance by a small dry battery giving approximately 200 volts. When the switch is closed, the battery charges the condenser until the voltage has risen to the breakdown value for the neon tube. A low-impedance path is then presented for the discharge of the condenser. The discharge proceeds until the minimum critical voltage is reached. The tube then ceases to conduct, the battery begins to charge up the condenser again, and the operation repeats itself. When the characteristics of the circuit are properly adjusted, the period of pulsation is directly proportional to the resistance in the battery circuit and to the capacitance of the condenser, and is almost independent of fluctuations in the battery voltage if the latter is above a certain limit. In the instrument for testing timber, two similar circuits are used. In one a fixed resistance is employed in series with a fixed capacitance so adjusted that the light from the neon lamp pulsates with a period

of about 0·5 sec. In the other circuit, the resistance is replaced by the wood to be tested and the capacitance of the condenser is varied in steps by means of a selector switch. To carry out a test, it is merely necessary to insert standard electrodes into the wood and turn the selector switch until the pulsations of the two neon tubes approximately synchronize. The percentage of moisture can then be read off from the dial of the selector switch. The standard electrodes take the form of replaceable steel plates mounted in pairs at opposite ends of an insulated hammer-head. Pairs at one end of the head are at right angles to those at the other, so that the test can be applied to timber in whatever position may be most convenient. When the device is used for sorting timber, the selector switch is set to a given position and the rate of pulsation of the neon tube compared with the standard indicates whether the timber is above or below the standard of dryness required. The accuracy of resistance measurement by this method is, of course, not high, but as the resistance of wood varies very rapidly with changes in the percentage of moisture, the method enables the latter to be satisfactorily measured.

Measurement of Small Distances.

Electrical methods can also be applied to the measurement of small changes of distance and to engineering gauging. In mass production the use of "go" and "not go" gauges is very common, but it is useful at times to have an indication on a dial of the extent of deviation from a standard. For the measurement and recording of rapid movements or vibrations electrical methods are unrivalled, especially when the parts are inaccessible.

The principle of utilizing the variation in reluctance of a magnetic circuit with change in the air-gap has been applied to gauging in several cases where work has to be carried out within fine limits of size. In one method two similar test coils with iron cores and air-gaps are used. These coils are connected in two arms of an alternating-current Wheatstone-bridge circuit. In the other two arms are two adjustable resistances and two adjustable inductances. The bridge is fed through a transformer from a small 500-cycle generator instead of a battery, and a sensitive d.c. ammeter connected through a rectifier is used instead of a galvanometer. To calibrate the gauge, the air-gaps in the cores of the two coils are set to the same value, approximately equal to the one to be used in the measuring coil. By means of the adjustable resistances and inductances, the bridge can be balanced so that the ammeter reads zero or any other required value. The gap in one coil is then kept constant, and very slight alterations in the air-gap of the other (or measuring) coil will upset the balance and alter the reading of the ammeter accordingly. The moving gauge-point of the gauge affects the air-gap through a lever, and is brought into contact with the work by means of a spring. Calibration is performed by means of, say, two master gauges, one for each extremity of the range required; the corresponding deflections of the ammeter are noted. Any piece which produces a deflection between these two values is therefore within the desired limits of size. For gauging holes or cylindrical pins two fixed gauge points and a movable one may be used. On rotating the piece it is immediately obvious whether it is round and within what limits its size varies. The instrument can be made to give a deflection of 1 in. or more on the ammeter scale for a variation of 0·0001 in. in the position of the gauge point. Gauging can be carried out by this method with great rapidity and without fatigue. The circuit being a differential one, the readings are not greatly affected by small differences in the voltage of the generator.

An interesting application of the same idea is used for investigating vibrations, such as those of turbine discs while running at full speed. In this case, advantage is taken of the magnetic nature of the discs. The test coil may be fixed to a stiff bracket and brought into proximity with the disc whose movements are to be investigated. Variations in the air-gap cause corresponding degrees of unbalance on the bridge. The ammeter of the gauging apparatus which has just been described is replaced by an oscillograph, which is operated from the third winding of a differential transformer, the other two windings being in circuit with the test coil and the dummy coil respectively. The oscillograph is connected in series with an inductance and condenser so adjusted as to give dull resonance at 500 cycles per second. This makes the arrangement more sensitive and reduces disturbance due to harmonics.

By utilizing the movement of a diaphragm to alter the air-gap, as in the telephone receiver, the method may be employed for the measurement of rapidly-varying fluid pressures. It has been utilized in this way, for example, in investigations on cavitation in large hydraulic turbines, and for obtaining indicator diagrams of small domestic refrigerators.

Another variation of the device has been adapted to indicate the eccentricity of turbine shafts during starting-up operations. It is well known that when a large steam-turbine is shut down, the rotor does not cool uniformly all round; the hotter side, being longer, warps outwards temporarily, and it may be many hours before the rotor becomes straight again. If the turbine is started and run up to full speed while the rotor is still bent, there is a great danger of severe vibration being set up, and where the clearances are small permanent damage may be done. To avoid this trouble an instrument has been devised consisting of two similar transformers mounted close to the turbine shaft and on opposite sides of it, between a gland and a bearing. The magnetic circuit of each transformer includes the shaft and the two air-gaps between it and the shaft. Practically all the reluctance is concentrated in the air-gap. The two transformer primary windings are connected in series to a small high-frequency generator, and their secondary windings are connected in opposition across a copper-oxide rectifier which can be joined to a d.c. indicating or recording instrument. If the air-gaps of the two transformers are equal, no potential difference is produced across the terminals of the indicator; but if the shaft is running eccentrically, the air-gaps are periodically unbalanced and the rectified unbalanced voltage is indicated. An eccentricity of 0·001 in. can easily be shown. The indicator can, of course, be placed at any convenient position in the control room or elsewhere. Limits of eccentricity can

then be prescribed beyond which it is not advisable to bring the turbine up to speed.

X-Ray Examination of Metals.

The next subject I propose to mention is the application of X-rays to the examination of engineering materials, a matter which is becoming of greater importance in view of modern engineering developments, especially in fusion welding. A constructional tendency which is very noticeable nowadays is the replacement of castings by steel sections built up by welding. The frames of motors and the stators of large turbo-generators are interesting examples of this tendency, and there is also great scope for welded boiler drums if it can be proved that the welds are absolutely reliable when called upon to withstand the high pressures met with in modern practice. The primitive engineering method of testing samples to destruction is not satisfactory in this connection, and internal weaknesses may easily exist which are undetectable by the most careful external examination. Of the various non-destructive methods of inspection which have been suggested, the X-ray method seems to be the most promising and reliable.

The high voltages (up to 200 kV) necessary to generate X-rays of sufficient penetrating power for use in the examination of steel of considerable thickness are obtained from special oil-insulated transformers and valve rectifiers. The personnel employed in operating the X-ray apparatus have to be protected both from the dangers attendant on the use of the high voltage and from the risk of exposure to the X-rays. These are very injurious to the human body, their effect being cumulative. The question of protection is somewhat complicated by the fact that X-rays are scattered to a certain extent on passing through matter, just as a beam of light is scattered in passing through a fog. Hence it is necessary to guard against both the primary beam of X-rays and the secondary radiation from the sides. For this reason, the X-ray tube is either enclosed in a special box which is completely lined with lead about $\frac{7}{16}$ in. thick, and has a small aluminium window through which the working beam of X-rays can pass, or a special type of tube is used which carries its own protection. In this tube a long cylinder of glass is used instead of a spherical bulb. The centre portion of this is cemented into a steel tube completely lined with lead, except for a small window through which the X-rays can pass. The projecting ends of the glass tube are encased with insulating material, and the special cables are brought up to the tube in such a manner that both tubes and cables are shockproof. The introduction of the shockproof type of tube makes it possible for the complete apparatus to be constructed in a portable form for industrial application. This portable type can be applied with great facility without danger to the operator either from the high-tension circuit or from exposure to the X-rays.

In order to reduce the exposure time for industrial work, several devices are used. In the first place, the target or anti-cathode is cooled by water under pressure, thus enabling larger amounts of energy to be employed. Secondly, by using a suitably shaped cathode the focal spot is elongated so that a larger area of the anti-cathode is utilized, although the effective area—viewed from the direction of the useful beam—is still roughly square. In addition, intensifying screens of cardboard coated with a fluorescent salt are placed in contact with the photographic film, one in front and one behind, so that the sensitive film is affected not only by the X-rays directly but also by the radiation from the fluorescent screens.

When the exposures are properly timed, the radiographs reveal the presence of very small blow-holes and other defects with remarkable clearness. A standard by which the dimensions of defects can be estimated is obtained by covering the weld during the exposure with a thin steel plate in which a series of holes have been drilled to graduated known depths. If the darkening of the film due to the relative "transparency" of a particular blow-hole corresponds to the darkening under one of the calibration holes, it can be estimated that the extent of the blow-hole in the direction of the X-rays is very approximately the same as the depth of the calibration hole. With experience, differences of thickness of metal as small as 1 per cent can be detected in a steel plate 1 in. thick. The radiographs also indicate incomplete junctions, cracks, porosity, and other defects; stereoscopic methods can be used if it is necessary to ascertain the depth at which any particular flaw is situated. The radiograph system can be of great service in investigating and perfecting routine methods of electric welding. X-ray examination has been found very useful in the inspection of aircraft, e.g. for indicating whether studs have been screwed home and for finding out whether screws of the proper length have been used.

Applications of Thermionics and Photo-Electricity.

The last group of electrical applications with which I shall deal are based on the connection between light and electricity. About 45 years ago it was discovered that a negatively-charged insulated body, e.g. a polished zinc plate, rapidly lost its charge when a beam of ultra-violet light was thrown upon it. Under suitable circumstances the discharge so produced may be utilized to carry a current sufficient to perform many useful functions. For such purposes the apparatus is made up in the form of a photo-electric cell, which consists essentially of a cathode made of some photo-sensitive material and an anode insulated from it, both being sealed in an evacuated glass bulb. The anode is comparatively small, and the cathode may either take the form of a flat or concave plate, or the inner surface of the bulb may be coated with a film of metal whose surface is photo-sensitive, leaving a suitable window for the entrance of light. If the light-sensitive cathode be connected to the negative pole and the anode to the positive pole of a battery of suitable voltage, no current will flow across the evacuated space in the tube so long as the cathode is not illuminated. Immediately light is allowed to fall on the cathode, however, electrons are emitted and a small current flows. This small current can be amplified by means of a thermionic valve and made to operate an electromagnetic relay controlling a large power circuit.

The thermionic valve takes the form of an evacuated bulb containing a hot-filament cathode, a grid, and a

plate anode. A comparatively high voltage is maintained through the relay circuit between the cathode and the anode, and the relative ability of electrons emitted from the hot cathode to reach the anode depends upon the potential of the grid. The valve is so constructed that comparatively small changes in the grid potential, involving the flow of exceedingly small currents, produce large changes in the discharge between the cathode and the anode—and hence through the winding of the relay. The battery for operating the photo-electric cell has in series with it a very high resistance, one end of which is connected to the grid and the other to the filament of the valve. The result is that when the photo-electric cell is illuminated, current flows through it from the battery, producing a fall of potential between the ends of the resistance, and therefore between the grid and the filament of the valve. The consequent change in the valve current then operates the relay.

The photo-electric cell has been used for counting objects on a travelling belt during mass-production operations. For this purpose, a cell is arranged on one side of the belt and a beam of light is directed upon it from the other side in such a manner that objects on the belt intercept the beam as they pass. The cell operates a relay, which in turn actuates a counter.

It can be used for diverting special articles from a travelling main conveyor to any desired branch conveyors. This can be done by having two lamps at each branch conveyor, both focused on a photo-electric cell. The distance apart of the pair of lamps varies at the different branches. Two small flags are fitted on, say, the boxes which carry the materials, so as to intercept the beams of light. Each box will pass all the junctions at which its flags do not intercept simultaneously both beams of light, but as soon as it reaches a junction at which the lamps are set at a distance apart corresponding to the flags, all light is cut off from the photo-electric cell at this junction and the branch-conveyor diverter commences to operate so as to carry the box off.

The photo-electric relay can be used as a limit switch in places where a mechanical switch is liable to damage, as, for instance, to control the cutting of a hot bar passing through from a rolling mill.

It has been used in a paper mill to give an alarm in case of breaking of the paper. Two lamps are used, one for each edge of the web of paper, so that an incipient tear at either edge allows the light to reach the cell and give an alarm.

Other applications are in the control of the side lay of a web of paper during its transition to a bag-making machine. Warning is given when the web deviates more than a predetermined amount from the mean running position. A similar device is used for controlling the feeding of paper wrappers into a bag-making machine, in order to maintain the register with regard to printed matter on the paper.

There are two other valuable characteristics of the photo-electric cell. One is that within certain limits of light and voltage, the photo-electric discharge or current is proportional to the intensity of the light falling on the cathode. Besides being useful for indicating the density of smoke in a power-station chimney or for keeping a watch on the strength of a turbid solution, this property has been made use of in the construction of photo-electric photometers. These not only offer ease of operation, but are also largely independent of the differences in sensitiveness of the eyes of different observers. As a result of the accuracy and rapidity of this method further improvements in uniformity will no doubt be made in the mass production of electric lamps.

The other characteristic of the photo-electric cell is that its relative sensitiveness to light of different colours or wavelengths depends on the material of the cathode. Some materials, such as magnesium and calcium, are sensitive to ultra-violet rays but not to visible radiation. Others are more sensitive to the blue or the yellow. Cæsium has a maximum of sensitiveness for a colour not far from that at which the eye is most sensitive, and this element is therefore commonly employed as a sensitive film on the cathodes of photo-electric cells. By using two or more cells which have different sensitivities for different colours, it is possible—with the assistance of coloured filter screens—to devise methods for matching and defining colours, and it has been suggested that objects on a travelling belt might in this way be sorted out according to their colour.

The thermionic valve has many applications in addition to its use as an amplifier in connection with photo-electric relays. If a certain quantity of gas or mercury is introduced into the envelope of the valve it can act as a relay direct. With a given anode voltage there is a particular grid voltage which will just permit of ionization of the gas in such a valve, and as soon as this occurs the resistance of the latter apparently breaks down almost completely, permitting quite large currents—amounting to several amperes—to flow. Immediately the breakdown takes place, the grid voltage loses all control and the only way to stop the current is to reduce the anode voltage. If, therefore, one of these tubes is used as a relay in a d.c. circuit, some way must be provided of breaking this circuit before the relay is required to operate again. On an a.c. circuit the tube acts as a rectifier, and the current is of course interrupted automatically every cycle, so that the relay is self-resetting. A very useful feature of this type of valve on an a.c. circuit is that the average value of the rectified current can be modified by altering the phase of the grid voltage with regard to the anode voltage, because this determines the point in each anode-voltage half-wave at which the tube begins to conduct, and it goes on conducting only until the end of each half-wave. A very wide field of control by infinitesimally small currents has been opened up by the introduction of this device, and there is no doubt that it will be largely utilized in the future. To mention one example only, the speed of a small d.c. motor fed from such a valve can be controlled by altering the phase of the grid voltage.

SOUTH MIDLAND CENTRE: CHAIRMAN'S ADDRESS

By J. Morton, Member.

(*Address delivered at* Birmingham, 19*th October*, 1932.)

That "It pays to advertise" is a slogan which present-day competition has almost raised to the position of an axiom is beyond dispute. To suggest, however, that advertising had an adverse effect on the electric supply industry during its early days may seem strange, but it is nevertheless true.

The industry as we find it to-day is the result of an early appreciation of the advantages to be gained by the use of electricity, and if in these early days the question of generation and distribution had received as much consideration as is given to the subject to-day, present-day conditions within the supply industry would have been very different. The opening ceremonies of many of the early stations were, very naturally, occasions for much pomp and ceremony, as befitting such apparently progressive actions. The publicity thus given created in the minds of those responsible for the destiny and well-being of small adjacent parochial areas, vestries, and boroughs, the desire that they too should have their own electricity works. As a consequence, numerous undertakings came into being, irrespective of their geographical location, with the result that in many cases the areas served by the respective stations, each of small capacity, were within the limits of economical transmission at voltages for which a suitable type of cable was available even at that time. The demand on the various undertakings was therefore poor and the load factor correspondingly low, and these conditions made cheap generation extremely difficult in almost every case. Even to-day, after making allowance for the normal growth of these undertakings, load factors still remain so comparatively low as to affect adversely the possibilities of cheap power.

Why all these small undertakings were allowed to start working quite independently of each other, is difficult to appreciate. Had the supply industry as a whole been under the control or jurisdiction of some governing body fully conversant with all the technical and financial considerations appertaining to the industry, the success of which was inevitable, the number and variety of types of stations established in this country would have been considerably less. Further, the greater degree of uniformity in operating conditions thus rendered possible would have resulted in a considerable ultimate saving in capital expenditure.

During these early days, the authority for granting powers for the establishment of new supply undertakings and for sanctioning extensions to plant in existing authorized generating stations was vested in the old Local Government Board. The duties of this body were to investigate and decide whether the applications received for the expenditure of capital in this way were likely to conflict with the ability of the applicants to fulfil certain conditions already established for the protection of the community, who might be called upon to make good any loss resulting from the exercise of the powers sought. The present governing body examines not only from the economic but also from the technical point of view the question of the effect which new applications are likely to have on industry as a whole. The technical aspect was never seriously considered by the original governing body.

In order to show how the lack of attention to technical considerations has affected the present-day problem of cheap electricity, it is interesting to make reference to the statistics for the year 1930–31 compiled by the Electricity Commissioners. From these statistics we find that a total of 483 generating stations in this country are being operated by authorized undertakings; these stations having an aggregate installed capacity of 6 945 805 kW. Of this total 5 310 927 kW are installed in 94 stations each having a minimum of 25 000 kW or over, while the balance of installed plant is allocated to the remaining 389 stations, of which 197 have installed capacities of less than 1 000 kW. A fact which has for years constituted a continuous drag on the supply industry is that the aggregate maximum demand to be met by the total installed plant capacity now being operated by authorized undertakings, could be met with 83 per cent less plant than is now available. Even on the basis of the almost universal practice of retaining 25 per cent of spare plant at all times, we are still left with approximately 58 per cent of available plant which need never have been purchased had the taking of bulk supplies from a suitably-designed system been made compulsory in the early days, before an amount of low-efficiency plant much in excess of national requirements had been added. The result of all this uncontrolled development is that in addition to the very heavy capital expenditure now being incurred in order to provide a system of interconnection and distribution, the industry will, for quite a long time, have to bear the additional capital charges on obsolete plant which has still an appreciable book value.

Turning to the question of load factor and its influence on the cost of generation, it is to be hoped that the remarkably high load factors of several of our large base-load stations do not create a wrong impression, particularly in the minds of the large power consumers. Such consumers should remember that the price per unit which they are called upon to pay is governed by their own load factors, which bear no direct relation to the load factor obtaining in a particular station. The abnormally high load factors obtaining in certain base-load stations are not indicative of abnormal prosperity in the supply industry: on the contrary, they are only

possible as the result of particular operating conditions. These high load factors are only obtainable through a reduction in the figures of other less efficient stations, whose operating results must still be taken into account when calculating the load factor over the country as a whole. At the moment it is very difficult to arrive at a figure which will be truly representative of the average load factor for the industry. It is easy to obtain the maximum demand on each individual authorized station now in operation, but as the time function for the numerous stations varies over quite appreciable limits the simultaneous maximum demand is obviously not available; consequently we must content ourselves with an estimated average load factor. Fortunately, the necessity for estimating will soon disappear. The apparatus now being installed in order to fulfil the requirements of the Electricity Supply Act (1926) for the metering of all energy generated at selected stations may reveal a diversity condition which will be of material advantage, inasmuch as by suitable operation the difference in the times of maximum load in the respective regional areas may be taken advantage of, with a resultant delay in capital expenditure on future plant extensions.

A material increase in the average load factor would clearly mean the salvation of the electric supply industry, but without an improvement in the working of industrial undertakings, upon which the electricity supply undertakings are dependent for the major portion of their load, it is not clear to me how such an increase can be obtained. At the moment great hopes for a better load factor are being entertained owing to the increase in domestic supply, but, unless our manufacturing industries improve and continue to produce under improved conditions, the benefits resulting from such domestic load requirements cannot continue. The capital expenditure now being incurred to give such supplies can only remain remunerative so long as our manufacturing industries are sufficiently healthy to maintain in a reasonably prosperous state that section of the community which is responsible for the domestic demands. That the present-day industrial electricity requirements have been seriously reduced owing to bad trade is unfortunate, but in spite of this our manufacturing industries are still responsible for the consumption of at least 50 per cent of the total energy produced by the various authorized undertakings throughout the country, without taking into account the large amount of energy produced by private plants.

That such private plants exist is a misfortune from the point of view of public supply. It is highly probable, however, that if a genuine comparison of the costs of private and public supplies were made the owners of such private plants would realize that it would be in their own interests to take their requirements from the public supply mains. I do not suggest that this is true in every case, for where large quantities of low-pressure steam are available, or where low-pressure steam is required for process work, and providing that the electrical power requirements can be regarded as a by-product, there can be no question of a public supply competing with a private plant. The Billingham works of Imperial Chemical Industries, described in a paper* read before the Institution in 1930, is an excellent example of such a plant.

* *Journal I.E.E.*, 1930, vol. 68, p. 1233.

Returning to the question of our manufacturing industries, it cannot be denied that their condition—even under periods of maximum prosperity—is far removed from the ideal, and like the supply industry they suffer as the result of daily periods of inactivity. The result is that they are compelled to fix the price of the article or material manufactured at a figure high enough to meet overhead and other minor charges incurred during the inactive period. It is reasonable to assume that even in the most perfectly conducted industrial organization, conditions prevail which preclude 100 per cent production being obtained during an ordinary working day. It would therefore seem reasonable to fix the production factor at 90 per cent of its maximum. Since, however, this percentage only applies to a prescribed period governed by the length of a normal working day, which itself is approximately one-third of the total available time, we find that the average load factor on production is about 30 per cent, a figure very close to the corresponding average load factor for the electric supply industry generally. It is apparent, therefore, that unless some very radical alteration in the operation of our manufacturing industries can be effected the manufacturing and electric supply industries will probably never approach the ideal. Such a change cannot be brought about under the present conditions of working hours as laid down by law, and in the absence of legislation for controlling the establishment of factories numerous organizations each equipped for the production of exactly similar articles have been set up, with the result that our facilities for manufacture are hopelessly in excess of the demand in the open market.

In order that existing manufacturing facilities may be adjusted to meet all expected requirements, it seems to me that the only course available is to shut down completely a reasonable proportion of the total number of factories which are laid out for the production of similar material or apparatus, making the cost of the change a charge against the particular industry in exactly the same way as the ultimate cost of the "grid" transmission system is to become a charge on the electric supply industry. Further, by eliminating dead capital and operating the remaining factories on a double-shift basis the requirements of our markets could easily be met, while the increase in the total number of hours worked per day would bring about a very considerable decrease in overhead charges, thereby relieving industry of a serious financial burden and producing a corresponding reduction in selling prices. Such a scheme could not fail to be of material benefit to industry itself and to the community at large. The reduction in the prices of commodities would probably result in an increased demand for manufactured goods, with the result that more labour would be employed and there would be a corresponding reduction in the monies paid out in respect of unemployment benefits. A percentage of the latter might be obtained to augment the fund which would have to be established in order to liquidate the charges remaining in respect of disused factories. Quite apart from the advantages I have put forward,

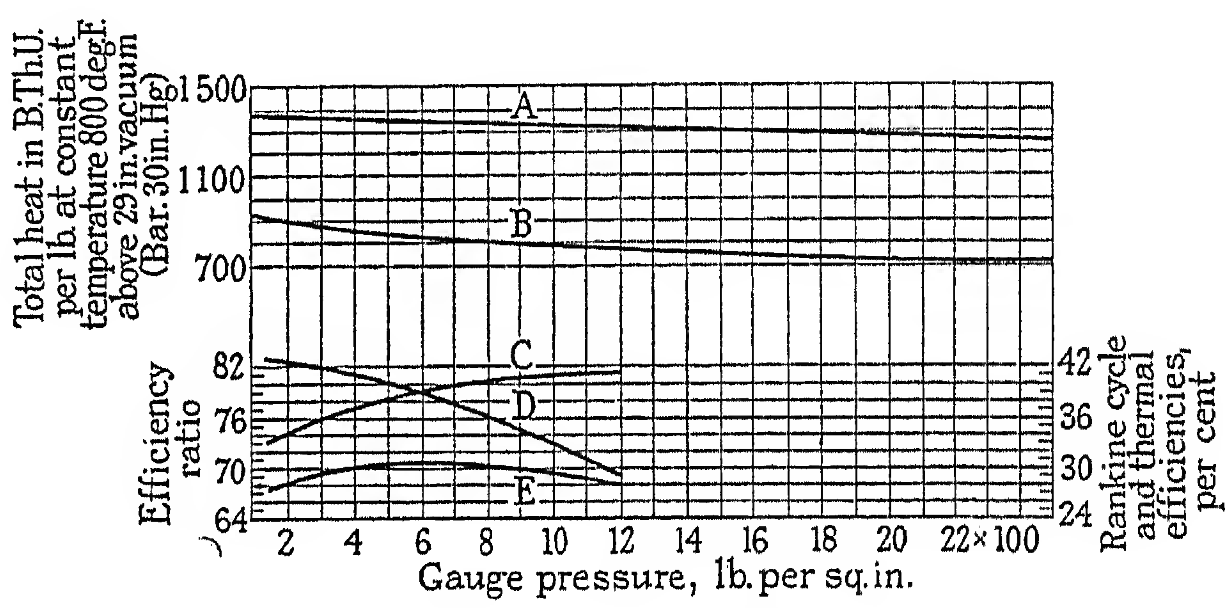
the resultant improvement in the load factor of generating stations would make itself felt by a material reduction in the fixed-charge component of the costs of generation, which, under present average load-factor conditions, constitutes a relatively large percentage of the total cost per unit generated. At present any effort on the part of the operating staff to obtain improvements in the efficiency of the plant at their disposal does not reflect the credit due to them, since such an effort is only applicable to a portion of the total cost which, under present load-factor conditions, may be less than one-half. It will therefore be apparent that unless something can be done to reduce to an appreciable extent the present fixed-charge component of our generating costs, the engineer will be precluded from taking advantage of the more efficient plant now available. Such plant constitutes the only means at our command for increasing the overall efficiency of generating stations and thereby reducing the quantity of coal required, thus assisting in the conservation of our coal supplies. A good deal of stress was laid on this latter point in the Weir report, which culminated in the passing of the 1926 Electricity Act.

The foregoing remarks with reference to the organization of our manufacturing industries so as to enable them to reap the real benefits which the electricity supply industry could—under better load-factor conditions—give, is not quite so revolutionary as it may at first appear. On the contrary, the merging of common interests has actually been accomplished in the electric lamp industry, in which the manufacturers, realizing the position into which they were drifting, actually pooled their resources. As a result we are to-day able to purchase lamps at prices considerably below those ruling prior to the change. It seems reasonable to suggest, therefore, that as concentrating the manufacture of lamps in fewer factories enables the manufacturers to sell them at a lower price, similar principles must equally apply to other manufacturing industries.

The conservation of our coal supplies is desirable, but what is of even greater importance to the electric supply industry is the means whereby better use may be made of the heat theoretically obtainable from the coal. The fraction of the calorific value of the coal which is actually available for conversion into useful work in our steam turbines is at the moment approximately $\frac{1}{4}$ in our best generating stations, and an even smaller figure in many other existing stations. It is not readily understood that such an uneconomical state of affairs is occasioned by virtue of certain thermodynamic laws and conditions established by Nature herself. It is well known, however, that these laws constitute the limiting features for the transformation of heat into mechanical work by means of the steam cycle, and as engineers we might reasonably be excused for suggesting that our adherence to the steam cycle for such transformation was far removed from the ideal. It may be that future scientific study and research will reveal a totally different cycle which will enable us to obtain a more equitable balance between useful available heat and the total heat as purchased in the form of coal. Even to dream of a new cycle other than that to which we have been so long accustomed is certainly revolutionary, but to me it seems unreasonable that Nature, having placed such stores of heat at our disposal, ever intended us to continue to work on a cycle which is responsible for so much wastage of her own resources. In the absence of a better-known cycle such as is now required, capable of converting large quantities of heat into the form of mechanical and electrical energy, we are compelled to adhere to and make the best possible use of our present knowledge, i.e. to take advantage of the more efficient plant capable of operating at higher steam pressures and superheats which scientific and industrial research has now made available for our use.

The important bearing which high-pressure steam and high temperatures have on fuel economy has long been known to engineers, and during the last 10 years a very material increase in working pressure has been effected. The choice of temperature, however, is not quite so elastic, owing to the alteration in the physical properties of materials working at high temperatures. To obtain the greater economies which result from a very high superheat is a matter of real difficulty.

With regard to high-pressure steam it is not always realized that, as the pressure increases, the total heat



in B.Th.U. per lb. of steam decreases irrespective of the degree of superheat, provided always that the initial temperature remains constant. To show that this is so, I have prepared a series of curves (see Figure). Curve A represents the total heat per lb. of steam at pressures from 200 to 2 500 lb. per sq. in., each with a constant initial temperature of 800 deg. F. above 79 deg. F., the latter being the temperature corresponding to an absolute back-pressure of 1 inch of mercury. The curve shows a marked diminution in total heat as the result of increased pressure, and that up to a pressure of about 1 900 lb. per sq. in. the fall in total heat practically follows a linear law. Beyond this pressure, however, the falling-off in total heat is more rapid.

Curve B has been drawn in order to show the available component of the total heat in B.Th.U. which is capable of being transformed into useful work. The curve represents the available heat drop at the various pressures, the heat drop being that resulting from perfect adiabatic expansion of the steam at the respective pressures down to a common final absolute back-pressure corresponding to 29 in. vacuum at 30 in. barometer. If, therefore, we compare the available heat-drop for each pressure and express it as a percentage of the total heat at the corresponding pressure, we obtain curve C, which represents the theoretical efficiency obtainable on

the Rankine cycle. The shape of this curve clearly shows the gradual increase in efficiency for each increment in working pressure, but it also indicates that if the pressure is raised beyond a certain value the improvement becomes less and less.

Let us now compare the theoretical efficiencies with those obtainable on a commercial turbo-alternator plant. The efficiency ratio as indicated by curve D shows the efficiencies which might reasonably be expected on a modern machine in converting the available heat shown on curve C into electrical energy at the alternator terminals, allowance having been made in the efficiency figures for all heat returned to the system as the result of feed-heating by means of steam bled at intermediate stages of the turbine.

By taking the product of the percentage efficiencies shown in curves C and D we are able to plot a further curve E, which represents the overall thermal efficiency obtainable at the respective pressures. It will be noted that this curve flattens out very considerably, and that between the pressures of 450 and 800 lb. per sq. in. the gain is so small that it is very doubtful whether the additional expense involved in installing plants for the higher pressures is economical. The curve shows that on the basis of a single uninterrupted expansion of the steam in the turbine, the maximum economy is reached at a pressure of approximately 600 lb. per sq. in. The factors which tend to reduce the overall thermal efficiency at pressures exceeding this figure are the increased gland and inter-stage leakage losses, but more particularly the rotation loss due to the higher steam density. Moreover, as the pressure is raised the temperature of saturation increases within certain limits, thereby reducing the amount of superheat which can be added to the steam. Owing to the reduced superheat content the dew point is reached at a much earlier stage in the expansion, causing an increase in the wetness factor of the steam which still further augments the internal losses, to say nothing of the damage to the blading caused by the presence of additional moisture. I wish, however, to make it quite clear that the falling off in efficiency beyond 600 lb. per sq. in. does not signify that the latter is a limiting pressure; on the contrary, the pressure limitation shown on the curve is merely the result which would be obtained by utilizing the steam in a single expansion. By interrupting the steam flow at a point in its passage through the turbine, extracting the whole of the steam, passing it through a reheater, and returning it to the turbine at a superheat temperature corresponding to the initial temperature at which the first expansion was commenced, the economic gain can be realized right up to the limits of working pressure.

So far as engineering practice in this country is concerned, the reheating principle has only been adopted in a few cases. As a matter of fact, many of the reheating plants now in commission are being operated at pressures considerably below 600 lb. per sq. in. I merely mention this in order to show that the reheat can be applied at any particular pressure, but although in the cases in question the principle of reheating was actually applied to machines whose initial working pressure is exactly the same as that of units of similar size which operate with a single uninterrupted expansion, the published results would indicate that the thermal efficiencies being obtained on the existing reheat plants are actually lower than on standard machines of similar size in which the principle of reheating is not incorporated. While the foregoing is a true statement of the thermal efficiencies now obtaining, it is definitely contrary to the results which should be achieved, since the reheating must of necessity increase the available heat-drop. It would seem, therefore, that other factors are coming into the problem which mitigate against the realization of the theoretical benefits conferred by reheating

In the United States a considerable amount of reheating plant is actually in service, working at pressures from 1 200 to 1 400 lb. per sq. in. The super-pressure units are in general of small capacity, and only make use of the heat in the super-pressure steam between the limits of initial pressure and a back pressure of from 300 to 400 lb. per sq. in., depending upon the initial pressure at which the main turbine plant operates. Although these small Pacer turbines exert an influence on the thermal results, they must be regarded as independent units and must be controlled on the electrical side. Despite the fact that the alternators of the Pacer units have but a fraction of the capacity of the main units, switchgear of equal rupturing capacity to that of the main units must be provided for their control and protection. If, therefore, the cost of such switchgear —including the necessary synchronizing arrangements for a large number of moderate-size super-pressure turbo-alternator units—is taken into account, it is quite conceivable that the slight gain in thermal efficiency will be found to be only obtainable at a high price. Another aspect of the problem is concerned with the fact that the material gain in economy becomes less with each increment in pressure. When steam turbines or other pieces of machinery are purchased very definite tolerance allowances must be accepted, and as these amount to a minimum of $2\frac{1}{2}$ per cent for a modern turbine the purchaser of a super-pressure plant may spend a considerable amount of money beyond that required for standard plant designed to operate at a moderately high pressure; yet the gain in efficiency resulting from the additional capital cost may easily be nullified by the tolerance alone, thus leaving the purchaser without any redress. From the purely engineering point of view there can be no question about the use of high pressures being attractive. We cannot, however, get away from the fact that high pressures mean increased initial cost; a turbine designed to operate with an initial steam pressure of 1 200 lb. per sq. in. may easily cost 25 to 30 per cent more than a turbine designed to operate with an initial steam pressure of 350 to 400 lb. per sq. in.

With regard to high-pressure boilers, the increase in price might even be greater than that of the turbine, since, owing to the high pressure, the capacity of the individual boilers which it is now customary to install would necessitate material alterations to present designs. For instance, the great volume of steam which would be required would necessitate large drum dimensions, and for the increased pressure it might be necessary to adopt a totally different formula for their design, and to use a formula more applicable to thick cylinders.

A further point which would mitigate against the possibilities of cheap boiler plant would be the question of the superheaters, which, owing to the abnormally high pressure, might have to withstand temperatures up to 850° or 900° F. Special steel would be necessary for their construction.

All things considered, it is obvious that if higher thermal economies are to be obtained, we must be prepared to pay higher prices, and since higher prices are reflected in our capital charges in respect of generation, there is little hope of our being able to avail ourselves of the advantages which high steam pressure and temperaperature make available, unless a material increase in our average working load factor can be obtained.

NORTH-EASTERN CENTRE: CHAIRMAN'S ADDRESS

By C. Turnbull, Member.

"SOME EARLY TURBINE REMINISCENCES."

(*Address, abridged, delivered at* Newcastle, *24th October*, 1932.)

In this Address I propose to give an account of the development of the steam turbine based on memories of the days when I served my time in the works of Messrs. Parsons at Heaton, about the year 1895. They may be of interest in recalling a first-hand impression of some of the difficulties which had to be overcome in the development of the turbine.

In the original steam turbines made by Sir Charles Parsons the steam entered at the centre and flowed parallel to the shaft each way for balancing purposes. The speed was very high, but the d.c. generators ran satisfactorily, although the steam consumption was necessarily excessive. When Parsons lost control of the parallel-flow patents he developed the radial-flow condensing turbines in which the steam flowed over a number of discs in series in a radial direction, each rotating disc being alongside a fixed disc which carried guide blades. A number of turbo-generator sets were made to this design and installed in various electricity stations throughout the country, where they did good work for many years.

There is no doubt that Parsons felt the loss of the lengthwise or parallel-flow patents severely. I remember meeting him in the works one morning when he spoke to me of his pleasure at having obtained his patent rights back again. Just before his last voyage he wrote me a personal letter in his own hand in reply to certain remarks of mine on invention, and closed with a reference to Edison's statement: "Invention is 5 per cent inspiration and 95 per cent perspiration."

Early a.c. generators were made with rotating armatures and stationary field magnets, and Parsons adhered to the rotating-armature design for quite a long time until growing difficulties compelled him to adopt rotating fields. The armatures were swathed in insulation and bound over with piano wire. The latter used sometimes to break and fly off, wrecking the machine. One of the difficulties of the turbine was that it was naturally most suited for large sizes, but in the nature of things it had to be developed through small sizes where the reciprocating engine was very suitable. Fortunately, in those days the Belliss and Willans engines had not been developed to their later state of perfection; if they had been perfected earlier it would have been difficult to have placed the turbine on the market. As the turbine got bigger, troubles began. When some 350-kW sets were made for Manchester Square, London, troubles began in earnest. I told Sir Charles Parsons shortly before his death that we in the works at the time considered the turbine had reached its limit at 350 kW: indeed, we thought that size too big, a fact which interested him. The bearings of these sets gave trouble. The journals were then long and thin, and consisted of separate pieces of metal forced into the main forging. I have an idea that there was some springing, and that the journals did not bear equally all along the bearing. At any rate, they gave trouble and sometimes broke. This might have been the end of the steam turbine for the time being had it not been for the introduction by Parsons of the idea of forced lubrication, an idea which compares with George Stephenson's plan for obtaining induced draught from exhaust steam, and it put the turbine on its feet.

The experiments with steam turbines involved the entry into a new and unexplored sphere of work. Mild steel discs were run under stresses that no one could calculate, and no one knew whether they were safe. If more had been known about them, I doubt if some of the work would have gone on as it did. The early condensing turbines had a frequency of 80 and ran at 4 800 r.p.m. The blades were caulked into grooves. I am quite sure that an ordinary engineer would not have been prepared to adopt a design of this sort: he would certainly have wanted to have the blades held in position in a mechanical manner. Nevertheless the caulking process was satisfactory, and rotors manufactured in this way did years of good work once the men had learned how to caulk them in properly. The early discs frequently became slack on the shaft, owing to the expansion of the metal. They were then bushed and replaced, and it is interesting to note that this method of expanding a disc by over-speed running has now come into everyday use. One of the astonishing features of the development

of the early steam turbines was that accidents were few, undoubtedly owing to the wonderful care taken in experiments. I remember once being in the test house when a turbine ran away. I was standing quite near to it, and when I heard it running up I felt that my last moments had come. Fortunately, Dr. Stoney was near and he rushed to the stop valve and shut it down.

The high-speed drive introduced a host of other difficulties. At that time armature reaction was a mysterious terror which was invading the domain of electrical engineers. Low-speed alternators were built which would not take full load because after three-quarters load the armature reaction overcame the field and the voltage began to die down. The same trouble affected turbo-generators. Designers did not wish the field to be too strong because this encouraged eddy currents. On the other hand, when the field was weak the armature-reaction trouble cropped up. The difficulties were intensified with direct-driven d.c. machines. The trouble was overcome in some of the early turbo-generators by the heroic method of cutting a slice out of the yoke so as to introduce an air-gap. An immense amount of work was done to make d.c. generators satisfactory. Brushes were made to move automatically with variation in the load, being actuated by the steam pressure, and Parsons invented special windings to overcome armature reaction. A further difficulty was that, owing to the springing of the shaft, the connections between the armature and the commutator gave trouble. This was overcome by the use of the flexible connector, a device introduced by Parsons. He made a curious slip when engaged in designing these connectors. He worked out that, owing to the fact that the connectors to the commutator only carried current for a very minute portion of the time, the density could be run up to about 30 000 amperes per sq. in. He had forgotten, of course, that the heat increases with the square of the current, and the early-pattern connectors were speedily burnt out in actual use.

Possibly some people might smile at the idea that a man like Parsons should have overlooked the square law, but, if they do, it is only because they have not indulged in research work. The field of research is strewn with experiments which have failed owing to the fact that those engaged have overlooked something which ought to have been obvious. The interesting point about this story is that Parsons was never frightened of high numbers. Any practical engineer would have been pulled up by a current density of 30 000 amperes, as any marine engineer would have been pulled up at the idea of running propellers at 2 000 r.p.m. Parsons had a grasp of mathematical fundamentals and he never allowed himself to be diverted from his experiments because they did not fit in with everyday ideas. I think that most engineers were very pleased when a.c. supply supplanted direct current, as the d.c. generators operating at 3 000 r.p.m. were not at all satisfactory for large loads.

I am indebted to Dr. Stoney for information concerning the experimental work done on the "Turbinia," which marked a new era in marine propulsion. The "Turbinia" was in the first place fitted with a radial-flow steam turbine which ran at from 2 000 to 2 500 r.p.m. Propeller after propeller was tried but, as all practical people then expected, the speed was too great. The propeller churned a hole in the water owing to the phenomenon known as "cavitation," and it was impossible to attain a speed higher than about 20 knots. Fortunately Parsons at that time recovered control of the parallel-flow turbine patents. He then placed three turbines in the ship, giving three shafts, and introduced the entirely novel and daring design of placing three propellers on each shaft. The nine propellers were each of 18 in. diameter and 24 in. pitch. The "Turbinia" travelled at the then unexampled speed of $28\frac{1}{2}$ knots, and, after further improvements such as a bigger funnel, etc., she did 34 knots. The turbines ran at about 2 500 r.p.m. The boiler heating surface was 1 100 sq. ft. and the evaporation 33 000 lb. of water per hour—an extraordinary figure for a little boiler of this type. The pressure on the water gauge in the stokehold was 11 in., and 130 lb. of coal ("Nixon's Navigation") were burned per sq. ft. of grate area per hour. The boiler, which was of the Yarrow type, was provided with a superheater, but this had to be removed as it ran red-hot, although placed beyond the water tubes. The bottom tubes of the boiler were made of steel castings, in halves. When the boiler was first put together it leaked, but the difficulty was overcome by putting some sal-ammoniac in, which rusted up some of the leaks: the worst ones were plugged.

In recalling these distant events, I cannot but bear testimony to the work done by Dr. Stoney and the staff generally in the development of the steam turbine. Only men of great fidelity and ability could have gone through with these early experiments. At that time I had very little hope of seeing the marine department of the works ever come to anything. I had every confidence that the turbine would justify itself for electrical work, but for marine use there appeared to be no possibility of success.

The "Turbinia" made her appearance at a great naval review, and it has been said that when she was doing 34 knots she was chased in vain by a police boat that wanted to haul her up for exceeding the speed limit. Subsequently, the "Viper" destroyer was built. She had a maximum speed of approximately 37 knots and was a great success. Everything appeared to lead to the speedy triumph of the steam turbine. Unfortunately, the "Viper" went ashore in the Channel Islands and was a total wreck. Then came the great disaster to the "Cobra," which nearly broke the hearts of Parsons and all concerned with the marine steam turbine. The "Cobra" was built on the Tyne and was fitted with the latest design of steam turbine. On her success hung the future of the turbine. If she did well, orders were likely to pour in, but if she failed it meant a return to the wilderness. After trials off the Tyne, she went on a trip to the South. One man whom I knew was going in her, but at the last moment he was replaced by someone in authority. He came home in a very bad frame of mind and expressed his disappointment in vigorous language. Then came the dreadful news that the "Cobra" had broken in two and gone down, taking most of her crew with her. All of them were picked men, and many were in high positions. One can only be thankful that

Parsons himself was not on board. Even at this time, so many years afterwards, those who were in touch with the "Cobra" cannot speak of the disaster without a feeling of dismay.

For a time the naval authorities would have nothing further to do with the turbine. Some had a feeling that possibly gyroscopic action of the turbines had produced too great a strain on the vessel, but one may say now that the trouble was due to the unsuitable design of the ship itself. Parsons showed that it could not have been due to gyroscopic action.

He himself, however, did not give up the invention even after this disaster. He arranged for a river steamer, the "King Edward," to be built on the Clyde, and she was succeeded by a further vessel named the "Queen Alexandra." These were both highly successful. They were followed by the English Channel steamer "Queen." Many people at that time were afraid that the turbine ship would not be suitable for the heavy weather often met with in the Channel. It is told, however, that on one occasion a paddle steamer (paddles were the ordinary method of propulsion for these Channel boats then) had a very long and arduous passage from France. Long after she had left the French coast, the turbine steamer set off and made the passage so quickly, in spite of the bad weather, that those on board were able to catch the same train as the paddle-boat passengers. This experience established the superiority of the turbine. One need not recall the "Carmania" and the wonderful "Mauretania," names which will go down to history.

The development of the marine steam turbine was very useful in providing information as to the ability of low-pressure steam to do useful work. In marine practice it became necessary to divide the turbine into a high-pressure and a low-pressure section. At that time steam-engine experts were unanimously of the view that when steam had been expanded to about 25 in. of vacuum it did not pay to make it do further work. To get a higher vacuum meant an immense increase in condenser equipment, and this was not worth while. On the other hand, the theorists said that there was useful energy to be got from steam at 25 in. of vacuum; but, as all those engaged in practical work then believed, "an ounce of practice is worth a ton of theory." Parsons really invented the means of getting work from low-pressure steam, and the world owes much to him for this.

The invention of the balancing dummy piston on the steam turbine marked an astonishing departure from the then existing practice. There was probably not an engineer in the world except Parsons who would have made use of the dummy piston. Everyone was accustomed to a piston which was a tight fit, and the idea of using a piston which obtained its tightness by means of thin strips not touching each other seemed so absurd that all the older engineers shook their heads and looked on it as a farce. Parsons was greatly puzzled in his early days by the problem of how to balance the end thrust of his turbine. I have been informed that a workman suggested to him that he could overcome the difficulty by making the turbine double-ended, and the early turbines were made on these lines. Ultimately he invented the balancing piston, which is now universally used. In the first example, the steam that leaked past the balancing piston went into the condenser, and doubtless this accounted for a considerable amount of the consumption of the turbine. When Parsons recovered the lengthwise-flow patents he arranged that the steam passing the high-pressure balancing piston should be used in the lower parts of the turbine, and this greatly improved the efficiency. We have now become accustomed to the labyrinth packing and take it as a matter of course; but it was a wonderful invention, and it would be greatly to the advantage of engineers if they were brought up to recognize the value of work of this sort.

Amongst the many inventions that came from his factory, one of the greatest was the means for balancing high-speed machinery. The low-speed machines of that day had big shafts held in ample bearings, and, as the rotating part revolved at a comparatively low peripheral speed, it was possible to keep the running in order by merely making the shafts and bearings sufficiently substantial. The turbine involved the introduction of very long rotors running at thousands of revolutions per minute. The journals for these long rotors were small and of a flimsy appearance. Ordinary ideas of balancing did not apply. It was possible to have a long rotor balanced quite perfectly from a static point of view and yet seriously out of balance when it was in service. The balancing troubles were further increased by the fact that the electrical insulation was then largely made up of insulating tapes and other soft materials, which were liable to change their form with the lapse of time, particularly when they were heated. Experience also showed that these high-speed machines store up dust in the ventilating passages. The problem of balancing involved an accuracy of workmanship that was then unknown in workshop practice. I remember an old turner coming to me in the factory and pointing out that he had to turn something to the size of a gauge plus the thickness of a piece of thin paper. He was wondering what the world was coming to. Grinding had not then been developed, and the ordinary turner of that day thought he did pretty well to keep down to $\frac{1}{64}$ inch. Any final polishing-up was done by filing the metal as it was turning round in the lathe, but this process was a refinement only intended for special work.

I remember one of the early big rotors which we could not balance. It was of the then gigantic capacity of about 500 kW. It was mounted in spring bearings and run up to speed, but the vibration was terrific. I was trying to balance the rotor, using the method of holding a pencil near it as it rotated; the pencil marks made in this way indicated the light side. Balancing weights were then caulked in for the purpose of getting the rotor to rotate without vibration. Parsons came along when I was busy with this rotor, and he gave prompt orders to have it taken out of the spring bearings and put into the lathe, where it was discovered that the machine for punching out the plates had been out of order and that the plates were in fact not properly centred.

The early days of the steam turbine were great days, hard days, and often heartbreaking days. There was a time when it was doubtful whether the steam turbine would win through at all. The story of Parsons and his work is one that should be told the world over.

NORTH MIDLAND CENTRE: CHAIRMAN'S ADDRESS

By R. M. LONGMAN, Member.

(*Address, abridged, delivered at* LEEDS, *25th October*, 1932.)

Before passing to the main subject of my Address, which will deal with the progress of the electrical industry during the last 30 years, I should like to support the idea of a common place of meeting for all the engineering institutions and technical and scientific societies, in which the various societies could hold their general and committee meetings, other bodies being invited when the papers are of joint interest. The various bodies should collectively provide a library and a permanent secretary, who would be at liberty to collect information for any society or member.

Such an institution, known as the Cleveland Scientific and Technical Institution, has been in existence at Middlesbrough since 1921. It came into being as the result of the exertions of the late Dr. Stead, the Cleveland Institution of Engineers, and others, who obtained donations from a large number of engineering and shipbuilding firms and from private sources. The building was formerly a chapel, but was converted to provide a library, reading-room, one large and one small lecture-room, a billiards-room, a canteen for light refreshments, and office accommodation for the secretary. Such a building provides opportunities for meeting and exchanging views with members of the different societies, and also for combined action on scientific or engineering matters of public importance. It might, with advantage, induce or assist men of technical or scientific attainments to take a wider and greater interest in municipal matters.

The period which I now propose to review is surely one of unprecedented development in electrical matters. I shall deal first with power-station progress.

Generating Plant.

One of the first large turbines for power supply was installed at Neptune Bank station, Tyneside; it drove a 1 500-kW 1 200-r.p.m. 6 600-volt generator having a revolving armature, the slip-rings being enclosed in a glass case. Its life was short, but the experience with the turbine caused a well-known engineer to say, "There will be a bigger craze for turbines than there is for water-tube boilers, and much more justification for it." Progress since those early days is represented by the fact that in this country we shall shortly have units of 75 000 kW, while in America compound units of 200 000 kW are in use and a single-line set of 150 000 kW is under construction.

Until recently, generating voltages were limited to the normal system pressures, chiefly 6 600 and 11 000 volts, but with the advent of larger units and transmission schemes higher voltages are being used. The following are some of the reasons in favour of adopting higher alternator voltages. (*a*) Reduction of mechanical stresses on the windings under short-circuit conditions; (*b*) higher current densities permissible for the smaller conductors; (*c*) greater simplicity in making the cable connections to the alternators for the smaller currents; (*d*) lower cost and less difficulty in construction of the necessary switchgear. A possible means of eliminating (*c*) and (*d*) is to construct the alternator and transformer as one unit, although I have not heard of this being considered.

Boiler Plant.

In 1900 the water-tube boiler was seriously competing with the Lancashire or large cylinder type, largely on account of its quicker steam-raising properties. A boiler capable of producing 20 000 lb. of steam per hour at 160 lb. per sq. in. steam pressure was then considered to be a large unit. Most modern power stations now have units of 80 000 to 100 000 lb. per hour at pressures of 300 to 400 lb. per sq. in., superheated to 750°–800° F., whilst in some very large base-load stations boiler units of 250 000 lb. and even 400 000 lb. per hour are being installed, and steam pressures of 1 000–1 400 lb. per sq. in. are in use in a number of stations.

One of the more important recent developments in boiler design is the use of water walls, whilst another is the more debatable advantage of the adoption of pulverized fuel.

Switchgear.

The advance in switchgear is probably the most striking electrical development of all. In the early days switchgear was looked upon as a necessary adjunct but it was tucked away anywhere—only the metering equipment received less attention. Now it demands accommodation almost as large as, and in some cases larger than, that for housing the turbine plant. The increasing size of the switchgear has necessitated first remote mechanical control and then remote electrical control.

The most outstanding developments in switchgear design have been (*a*) metal-clad gear (an all-British achievement); (*b*) outdoor switchgear, chiefly for voltages of 33 000 volts and above. The provision of suitable testing plant for switchgear should lead to considerable improvements whereby the rupturing capacity will be increased, or, alternatively, the size and cost of switchgear for a certain rupturing capacity will be reduced. There is still considerable room for fresh developments in switchgear design, notably in the direction of compressed-air-break and water-break types.

Transformers.

Transformer sizes have increased from about 200 kVA at 10 kV on the high-tension side to 80 000 kVA at 132 kV in this country and up to 250 kV in other parts

of the world, whilst testing transformers to give 1 000 kV are in regular use.

It is interesting to note that there are numerous transformers still in use in this country with 25 and 30 years' life to their credit, and I have seen a transformer built in 1898 which was in use until about three years ago. The adoption of forced cooling is the chief item accounting for the large increase in rating. No striking improvement appears to have been made in the actual magnetic qualities of the iron or in the design of the magnetic circuit.

Cables.

The use of paper as the insulating medium for high-tension work had already been adopted in 1900, although the original Ferranti gutta-percha cable—Greenwich to the City—was still operating at 10 000 volts until a few years ago, and it is only within the last 10 or 12 years that noteworthy progress has been made in either voltage or size of conductor.

The development of " super-tension " cables has been somewhat chequered, but a large number are now giving satisfactory service, some at 33 kV and some at 66 kV, whilst a few cables are in use at 132 kV.

Valuable information concerning the heating of buried cables has been obtained from tests carried out by the Electrical Research Association; the results are of particular importance in arranging the lay-out of the cables in large power stations, so as to avoid overheating and to obtain the maximum rating for the cables. This matter is of exceptional importance in the very large stations, and these conditions are in turn much improved by the adoption of higher generating and transmission voltages.

Overhead Lines.

The development of overhead lines in this country has been largely dependent upon wayleave facilities, the conditions being considerably eased by the Acts of 1919, 1922, and 1926. The chief technical detail has been that of insulators, and the adoption of the suspension type has made it possible to employ any desired voltage. For the actual conductor, copper has given way to steel-cored aluminium and copper-clad steel for the higher voltages and longer spans, with cadmium copper as an alternative for medium-voltage lines, and galvanized iron for cheap 6 600–11 000-volt lines in rural districts.

Instruments and Metering.

The advance in this direction has been almost phenomenal, and it has been accompanied by a corresponding change in the views of station engineers. Some of the most important technical improvements are due to the discovery and adoption of high-permeability alloys. The design of protective apparatus has received particular attention, and it is an essential and important part of the large transmission systems now in use. Many of the complicated instruments and metering equipments adopted in modern practice can only be justified by their large capacity, i.e. by the large exchanges of money which they certify. Great advances have been made in the use of electrical energy, which has proved a boon both to the public and to industry.

Lighting.

In 1900, carbon lamps dissipating 4 watts per candle-power, and arc lamps of various types, were the chief electrical illuminants. The first flame arc lamp, the Bremmer, was installed on the Westinghouse offices at the corner of Norfolk-street in the Strand. The flame arcs, the tantalum lamp taking 1·8 watts per candle-power, the tungsten filament, the drawn-wire metal filament ($\frac{1}{2}$ to 1 watt per candle-power), and the gas-filled lamps have followed in turn, and now we are promised an even more economical type. Mercury-vapour, neon and other types have also played a large part in the great advance of the standard and science of illumination. There has been a noteworthy advance in the direction of the creation and adaptation of new illuminants, whose value in the home, shop, street, and factory cannot be over-estimated.

Heating.

There is still a considerable field for the development of electric heating, although there has been a substantial advance during the period under review, especially quite recently in connection with industrial and domestic heating.

Power.

There are thousands of everyday examples of the adoption of electric power, the sizes of the motors used varying from a few watts up to 20 000 kW. Brief reference must be made to the adoption of electric power in collieries for working fans, pumps, haulage, winders, and coal-cutters. A further development is the use of the various types of electric furnaces for the manufacture of nitrates for fertilizers or explosives, and for the production, refinement, and heat treatment of metals, alloys, and porcelain.

Electrochemical processes of many kinds are now extensively employed, such as for the production of sodium and potassium and their hydroxides, and for electroplating and electrotyping.

The application of the electric drive to marine propulsion is making steady headway. Electrical working of main-line railway routes has not come up to some expectations, although electrification is now generally adopted on suburban routes where the traffic density is great, particularly at rush periods. A solution of the problem of main-line electrification may be effected by the commercial development of a new type of battery; if such a battery is developed and adopted only short sections of electrified track will be required. These will serve the dual purpose of driving the train and charging the batteries, which will carry the train on to the next section.

Telegraphy and Telephony.

The outstanding development in communication by wires is the advent of the automatic exchange, which is rapidly ousting the manual system both on the Post Office circuits and for the larger inter-office and works exchanges. The insistent ringing of the automatic system compels immediate attention, and it has been said that this is the chief reason for the quicker service which it obtains.

The speed and commercial capacity of submarine and long-distance telegraph circuits has been greatly increased by the adoption of automatic relaying apparatus, and of inductive loading to balance the capacitance of the cables.

Domestic.

Domestic applications of electricity, though very lightly cultivated for many years, really provide the widest field for development. Domestic electrical appliances bring great assistance to the housewife, and their value is often realized only when they are unobtainable.

Medical.

A development whose value to mankind cannot be estimated is the application of electricity in medicine and surgery for the elimination of suffering.

Other Developments.

Radio Communication.—Wireless telegraphy and telephony, picture transmission, and broadcasting, are among the most wonderful achievements of the period under review, and they all grew from two tiny seeds—the discovery of Hertzian waves and of the thermionic valve.

Mercury-arc Rectifiers.—Another development, the mercury-arc rectifier, started with the use of a stream of mercury acting as a quick make-and-break. Mercury rectifiers or convertors are now obtainable with capacities as large as 16 000 amperes and for voltages up to 12 000 volts. The combination of the valve with the mercury-arc rectifier—the grid-controlled convertor—opens up a still wider field; it makes possible conversions from alternating to direct current, from direct to alternating current, from single-phase to three or more phases, and from one frequency to another, and it brings the question of d.c. transmission into great prominence.

The Institution.—The growth of the Institution reflects to some extent the progress of the industry, and in this connection the following figures of its membership are of interest.

Year	Honorary Members	Members	Associate Members	Companions	Associates	Graduates	Students	Total
1900	4	970	644	—	1 624	—	419	3 661
1932	13	1 968	5 844	117	1 531	2 561	2 964	14 998

In concluding this portion of my Address I would mention our indebtedness to those engineers and physicists to whose labours—often carried on under very arduous conditions and with imperfect apparatus—we owe this wonderful progress.

The National Grid.

The construction of the grid in this area is practically complete, all the lines being maintained alive, a number of stations are regularly operating in parallel, and many regular or stand-by supplies are being given. This work has not been accomplished without the assistance, co-operation, and goodwill of the various

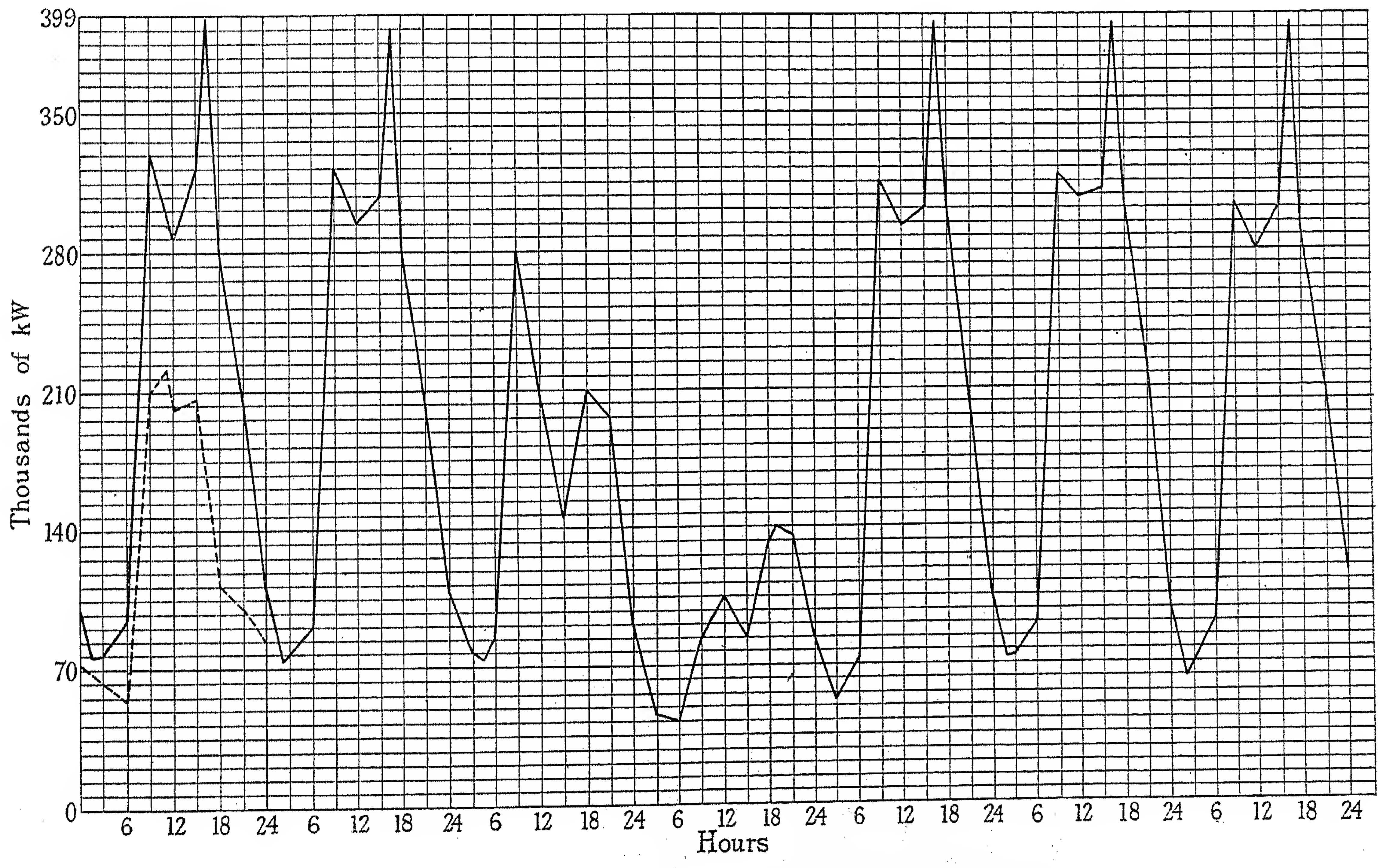


FIG. 1.—Load curve for 1931. Maximum demand sent out.
——— 17th–23rd December, 1931.
– – – – 2nd July, 1931.

undertakers, who have themselves carried out extensions and alterations to enable the connecting-up to be effected. The scheme will soon be in full operation in this area.

Under the 1926 Act the Central Electricity Board becomes responsible for all the costs—both capital and running—in connection with generation at certain selected stations. The success of the grid scheme is dependent upon (*a*) the growth of output, i.e. the increasing utilization of electrical energy; (*b*) the reduction in costs of generation due to the maximum use of the most economical plant compatible with the safety of the system; (*c*) the pooling of the spare plant in all stations, owing to their connection to the grid, which will appreciably reduce the amount of new plant required; and (*d*) the reduction in capital cost of new plant effected by the adoption of the largest possible units installed at points where coal and water are cheapest.

Although it has been stated that under the 1926 Act the Board has no power to close down a selected station, it is evident that in time it will no longer be economical to continue to operate all of the selected stations in this country.

The Board has taken up a praiseworthy attitude in insisting that the grid is really a co-partnership scheme. The money necessary to meet the expenses incurred by the Board is obtained from the undertakers in the form of a charge on all units, and any balances will be returned to them by a reduction of tariff. The State has no direct control over the Board or its finances, and it is for the undertakers and industry as a whole to ensure that the scheme is made a success and thus to give no loophole for the State to step in.

The operation of the grid in practice is of great interest; in Fig. 1 the full line gives the combined load curve of all the generating stations of this area for the heaviest load week of the year 1931, 17th–23rd December. The dotted curve shown is the combined summer load curve for 2nd July, 1931. Important figures for the year 1931 are given in Table 1.

TABLE 1.

Total units generated	1 279 millions
Total units sent out	1 213 millions
Sum of individual maximum demands ..	427 353 kW
Combined maximum demand (from Fig. 1)	394 940 kW
Load factor	35 per cent
Diversity factor of demands	108·2 per cent
Ratio of summer demand to winter demand	56 per cent
Ratio of night load to maximum load ..	15 per cent

Fig. 2, which gives the graded load curve for the year 1931, shows the total duration in hours of various loads. It may be of interest to explain how this curve is obtained. Fig. 1 gives the load curves for winter and summer, similar load curves are sketched in for each month, and from these the actual duration in hours per annum of each load is obtained and the curve shown in Fig. 2 plotted. The area under the curve gives a value for the total units per annum which agrees very closely with the actual figures for the year. The figures given in Table 2 are taken from the curve.

These figures show that plant for dealing with 20 per cent of the maximum load is required for only 250 hours of the year, and plant for dealing with 30 per cent of the maximum load for only 700 hours, i.e. for 88 days,

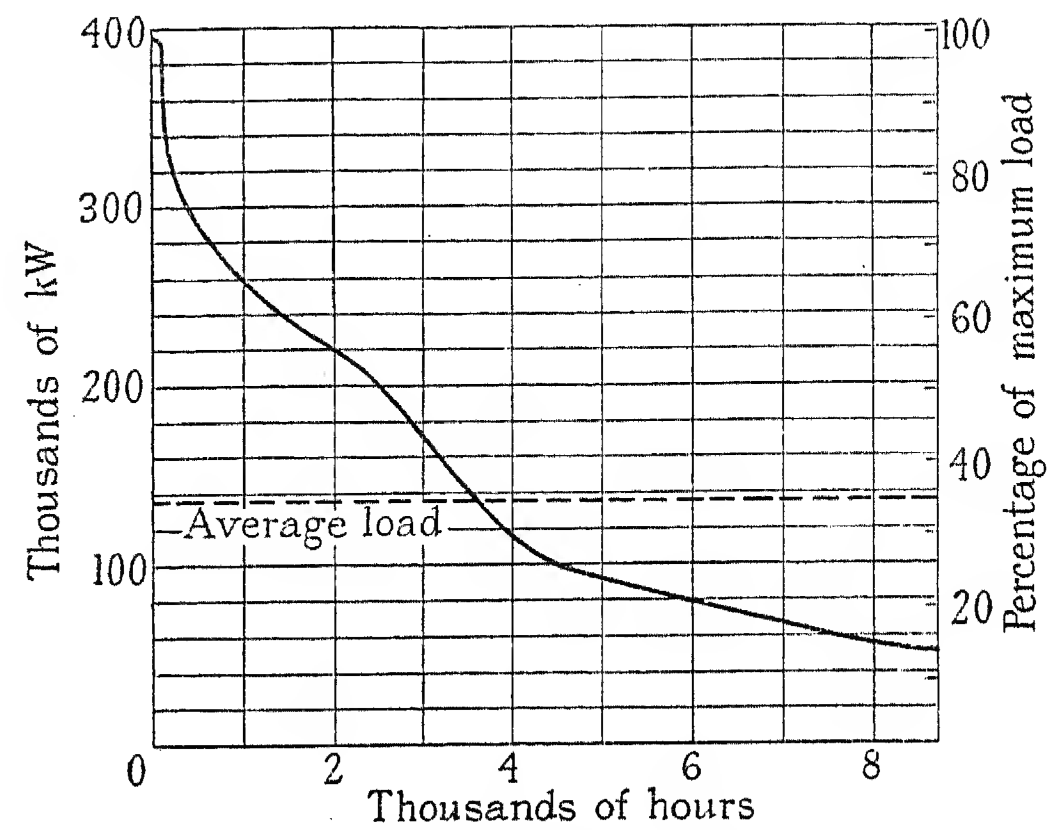


FIG. 2.—Graded load curve for 1931.

assuming it is required 8 hours per day, from 9 a.m. to 5 p.m. This is equivalent to 5 days per week for 18 weeks, say, for the months of November, December, January, and February. It is evident that the highest-efficiency plant is not essential for this short service. It

TABLE 2.

Load, as percentage of maximum demand	Duration, hours	Duration, as percentage of total hours per annum
90 to 100	100	1
80 to 100	250	3·9
50 to 100	2 600	30
exceeding 35*	3 600	41
below 35	—	59

* Average throughout the year.

does not necessarily follow that this peak-load requirement will be provided only by the plant in single-shift stations, as in many large stations which will be base-load stations there are less efficient units which can be used for this purpose; this is an advantage in that a smaller staff would be required.

Table 3 gives some interesting figures of plant capacity (in kW) for the selected and temporary arrangement stations in this area.

TABLE 3.

Total plant installed, 1931–32 ..	725 250
Maximum demand generated ..	441 400
Total spare plant	283 850
Total boiler plant	638 700
Effective boiler plant..	575 500
Effective turbine plant	657 000
Effective generating plant	528 000
Effective generating plant, revised ..	600 000

The figures for effective boiler and turbine plant are obtained by eliminating the oldest and least efficient units and by allowing for at least one of the largest boilers at each station being out of commission; the effective generating-plant capacity is thus less than the effective boiler-plant capacity, owing to the fact that in some stations there is not sufficient effective turbine plant to correspond to the boilers.

To allow one of the largest boilers to be out of commission at times of peak load is too generous, as under the existing conditions of loading there will be ample opportunity of carrying out all major repairs and overhauls before the winter peaks occur. A revised figure of 600 000 kW for the effective generating plant has accordingly been added.

would be when operating any of the stations at improved load factors, i.e. greater outputs. The fuel costs vary from 50 to 77 per cent of the total costs, but it is noteworthy that a low fuel cost does not necessarily mean a low total works cost.

Returning to the load curves, it is apparent that the filling-in of the valleys of Fig. 1 and the lower slopes of Fig. 2, in other words increasing the load factor, would be the least costly way of increasing the output and of bringing success to the grid scheme and to the undertakers.

In accordance with Section 11 of the 1926 Act, the grid tariff is to be a two-part one—i.e. a kW demand charge and a unit charge—and the tariff has to be fixed for a term of years. In this area it will be for 10 years.

TABLE 4.

Items of Works Costs in Pence per Unit, and Their Percentages of the Total.

Station	Fuel		Oil, water, and stores		Salaries and wages		Repairs and maintenance		Total
	d.	per cent	d.	per cent	d.	per cent	d.	per cent	d.
A	0·1566	48·5	0·0183	5·5	0·0978	30·5	0·0497	15·5	0·3224
B	0·1434	58·5	0·0011	0·5	0·0658	27·0	0·0348	14·0	0·2443
C	0·0805	77·5	0·0001	0·1	0·0123	11·9	0·0108	10·5	0·1038
D	0·1735	57·2	0·0025	0·8	0·0721	24·0	0·0551	18·0	0·3033
E	0·1749	56·8	0·0054	1·7	0·0624	20·3	0·0654	21·2	0·3081
F	0·1488	70·3	0·0026	1·2	0·0328	15·5	0·0273	13·0	0·2115
G	0·1559	71·4	0·0024	1·2	0·0360	16·5	0·0237	10·9	0·2180
H	0·1314	56·4	0·0026	1·1	0·0463	19·8	0·0530	22·7	0·2333
J	0·1856	61·7	0·0022	0·7	0·0706	23·4	0·0426	14·2	0·3010
K	0·1408	62·0	0·0017	0·8	0·0502	22·2	0·0341	15·0	0·2268
L	0·1348	58·3	0·0026	1·1	0·0319	13·8	0·0616	26·8	0·2309
M	0·2410	72·4	0·0029	0·9	0·0656	19·7	0·0232	7·0	0·3327
N	0·1405	63·6	0·0044	2·0	0·0499	22·7	0·0257	11·7	0·2205
O	0·1711	60·2	0·0097	3·4	0·0544	19·2	0·0486	17·2	0·2838
P	0·1787	62·0	0·0034	1·2	0·0518	18·0	0·0540	18·8	0·2879
Q	0·1348	59·7	0·0043	1·5	0·0342	15·2	0·0509	22·6	0·2242
R	0·1474	55·5	0·0110	4·1	0·0432	16·3	0·0638	24·1	0·2654
S	0·1755	50·5	0·0060	1·7	0·1014	29·1	0·0649	18·7	0·3478
Average	0·1401	62·5	0·0042	1·9	0·0399	17·8	0·0398	17·8	0·2240

Works Costs.

The works costs of generating stations are summarized under the following headings: (*a*) fuel; (*b*) oil, water, and stores; (*c*) salaries and wages; (*d*) repairs and maintenance. Table 4 gives the works costs of stations in this area for which the figures are available, and to facilitate comparison the percentage of the totals under the four items are given, in addition to the costs in pence per unit. It is noteworthy that the figure for salaries and wages is equal to that for repairs and maintenance. These two items show the largest variations, although they are quite unconnected with the size or output of the stations.

A total running cost of 0·1038d. per unit obviously indicates not only economical plant but also operation at a high load factor. From an examination of all the items and monthly returns it is possible to plot a curve showing with a fair degree of accuracy what the costs

It is evident that a tariff for such a period will show a deficit for the first few years, until some of the loan charges have expired and the pooling of the spare plant has allowed definite savings in expenditure and capital charges to be effected, but afterwards the accumulated deficit will be gradually wiped out and a favourable balance obtained.

The mere fact of having a definite fixed tariff settled for them for a number of years (even the owners of selected stations know that their energy will not cost them more than the grid tariff figure) will be of great assistance to the undertakers in arranging their own tariffs, and as the demand charge will probably apply only to the winter months it should prove an incentive to seek out and cultivate loads whose demands will not coincide with the winter peaks. This does not necessarily mean that such loads can be supplied by the undertakers

merely at a unit charge slightly above the grid figure, as the undertakers have their distribution, capital, and management charges to consider, but in such cases very attractive prices can be submitted.

Improvement in load factor practically means increased revenue without increase of capital costs, i.e. increased specific utilization of plant.

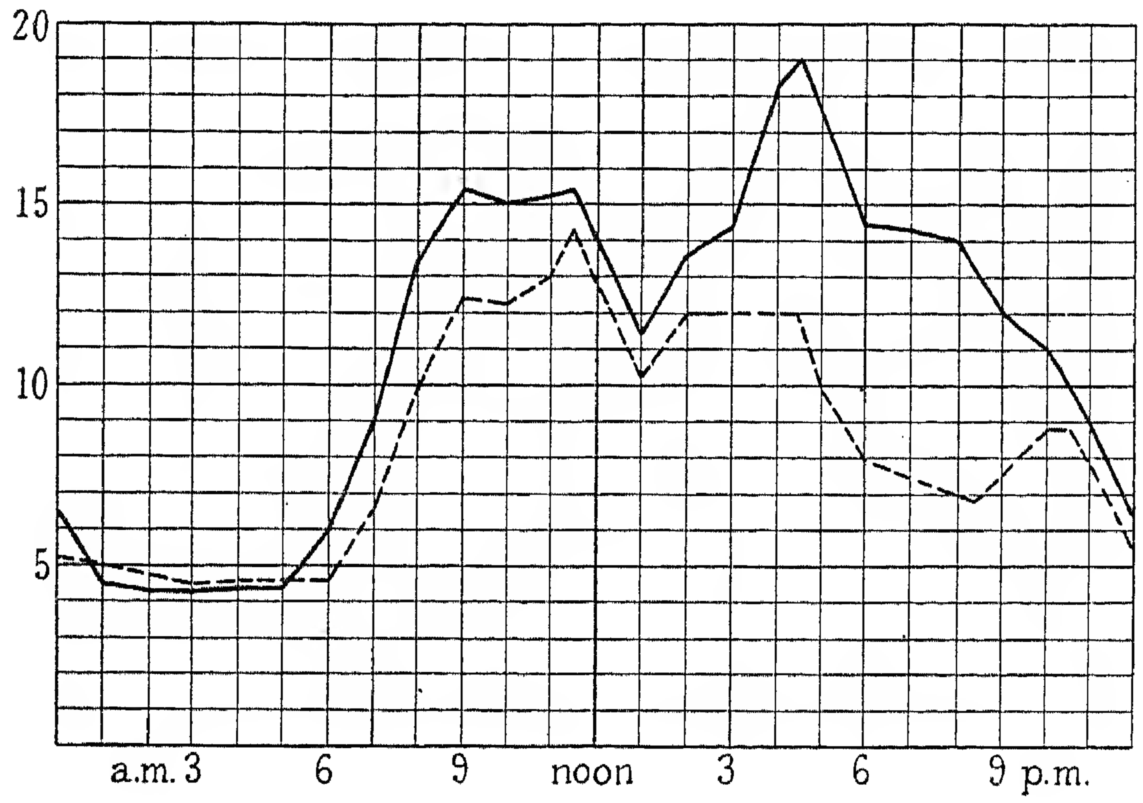


FIG. 3.—Summer and winter load curves.

Fig. 3 gives the summer and winter load curves for a progressive undertaking where all classes of load are well developed. It shows the summer peak to be 75 per cent of the winter peak, and the night load to be approximately the same in summer as in winter. The night load is 24 per cent of the winter maximum load, as compared with 15 per cent in Fig. 1. The small dip at midday represents a reduction of load which is only about one-third of the corresponding figure for, say, 10 years ago.

An improvement of the night load of this area from 15 to 24 per cent would be a big step forward; it would mean an increase of 140 million units per annum and an improvement of load factor from 35 to 39 per cent. It is this night load which is required, and the late Dr. Ferranti was right when he drew attention and devoted his energies to domestic water heating. The population of this area is approximately 5 millions, and, assuming 5 persons per house, the number of houses is 1 million. If 1 house in 5 could be induced to install an electric water heater taking 0·5 kW from 10 p.m. to 8 a.m., the additional night load would be 100 000 kW, which would practically fill in the whole of the curve in Fig. 2 below 150 000 kW.

The domestic load is an all-the-year-round load, in good times and in bad, and it is an even better load in summer than in winter, as the coal fire can be dispensed with entirely for the summer; but I fear it will be a long time before the use of coal or coke fires during the winter will entirely disappear. In the meantime the kitchen or sitting-room fire with a boot boiler will be in use and will provide a portion of the winter heating and hot-water supply. The domestic load is waiting to be obtained, and all those who are interested in the electrical industry should encourage the domestic use of electricity both by example and by precept.

EAST MIDLAND SUB-CENTRE: CHAIRMAN'S ADDRESS

By H. A. Nevill, Member.

(*Address delivered at* Loughborough, *4th October*, 1932)

I have on one previous occasion* had the honour of giving a chairman's address to a Local Centre of the Institution. This was in November 1916, when I was chairman of the Yorkshire Local Section. In considering what to say on the present occasion I reviewed some of the developments that have taken place in the generation and supply of electricity during the 16 years that have elapsed since the date of my last address, and it seemed to me that some comments on these developments might be of interest.

The far-reaching developments that have taken place in this 16-years' interval were caused in the first place by the urgent requirements that arose during the war period, and later by the demands for post-war development and the necessity for urgent economy in every direction.

The Electricity Supply Acts of 1919 and 1926 have probably done more to enable electricity supply to develop than any previous legislation dealing with this industry. The 1919 Act, which included the appointment of the Electricity Commissioners, gave supply authorities wide scope for extending their business and also (what is of great importance) for making arrangements for the joint operation of their power stations. Advantage was taken of these powers in some districts, but not to the extent which might have been expected. The 1926 Act has, by the establishment of the "grid," put forcibly into effect the ideas which were outlined on a more modest scale in the 1919 Act.

The establishment of the Central Electricity Board and of the national grid system will no doubt, in the distant future, be of considerable assistance to the country generally. It would appear, however, that the powers of the 1919 Act, had they been more fully made use of, would have given equally favourable results at a much lower cost, and have been more suited to the present economic conditions of the country.

The formation of the national grid was largely justified on the grounds of the saving in capital due to the better utilization of generating plant, in so far that much plant which had previously been kept in reserve could be put into operation, and also by the savings to be effected in coal consumption when the grid was fully in operation. There is no doubt that the first object will be achieved, but so far as the second is concerned the position seems to be becoming increasingly difficult. Since the figures which were used as arguments for the passing of the 1926 Act were produced, great economies in coal consumption have been achieved in the electricity industry, although the grid is not yet in operation sufficiently to have created the economies. The Electricity Commissioners' return for the year ended December 1931 gives the average fuel consumption per unit generated at steam stations as 1·82 lb. The return for the year ended 31st March, 1921, gave the corresponding figure as 3·32 lb. These figures seem to indicate that the margin for economy to be secured by the operation of the grid has been very largely reduced, and consequently the task of making the national scheme financially justifiable has correspondingly increased.

The economy in coal consumption has taken place not only in electricity supply stations but also in the manufacturing industries, in many cases as a result of these industries shutting down their own power plants and taking supplies of power from public mains. In the Peterborough area we have a very marked instance of this where in 1910 one industry alone had a weekly consumption of 323 tons of steam-raising coal. This industry was in the same position in 1919. In 1929 practically the whole of this local industry had discarded its own power plant, and was taking supplies of electricity from the Peterborough undertaking. Also the output of the industry in 1929 was more than twice that in 1910 or 1920, the difference between the figures for the two latter years being negligible on account of circumstances due to the war. If this industry had continued to generate its own power, on the lines of the earlier years, its weekly consumption of steam coal would have been in the neighbourhood of 650 tons.

Besides supplying the requirements of this industry the Peterborough power station also gave supplies to practically all the other manufacturers in its area, the maximum demands of two of them being between 700 and 1 000 kW. Energy was also supplied to the tramways, and to the general public for lighting and other non-industrial uses. At the time when the Peterborough station was carrying the whole of the load of this area the coal consumption never exceeded 750 tons per week. Further, the coal used was of a much lower grade than that previously used for steam-raising purposes in the industry referred to above.

The maximum demand for this industry in 1929 was 4 020 kW and the energy consumption 13·5 million units, whilst the maximum demand on the power station amounted to 9 250 kW and the station output to 28·3 million units.

The use of electricity in this industry meant better methods of working and economies in operation, owing to the ease with which the power absorbed in each section of the work could be measured.

On each of the large motors in use, demand instruments, provided with charts, were fitted in addition to the usual ammeter. These charts enable the user to ascertain where undesirable peak loads occur, and to

* *Journal I.E.E.*, 1917, vol. 55, p. 41.

take the necessary steps to eliminate them. The result is that to-day the energy consumption per thousand articles is considerably less than in the past, although the manual labour which was formerly used in dealing with raw material has been entirely replaced by electrically-operated plant.

Almost all branches of power-station equipment have developed very rapidly. Mr. McKenzie, in his chairman's address to the Manchester Local Section in 1916, stated that " in the near future one may confidently anticipate seeing units of 20 000–25 000 kW being installed in some of our large British stations."* In 1917 Messrs. Parsons built a 22 000-kW set running at 2 400 r.p.m. and the British Thomson-Houston Co. obtained an order for a 30 000-kW set to run at 1 500 r.p.m.; these were very large units for that time. To-day 30 000–50 000-kW sets are quite common in the larger power stations of this country, and 60 000–75 000-kW sets are now being installed.

In addition to the growth in size of units, the operating speed has been increased, so that to-day 30 000-kW sets running at 3 000 r.p.m. are becoming quite customary. A recent article relating to the newly-opened Scheele power station, near Antwerp, states that the first section of the station is equipped with three turbines each of 30 000 kW and that the second section will have a turbine of 60 000 kW running at 3 000 r.p.m.

A step forward has also been made in the generating voltage of these large units, and there are now several sets of 30 000 kW capacity generating at 30 000 volts. The increase in generating voltage naturally tends to economy in the provision of transformers, and, if adopted generally, should reduce capital expenditure and the space required for the installation of the plant.

The use of these large generating units combined with elaborate feed-heating arrangements has enabled improved costs of generation to be secured, and has also kept within reasonable bounds the size of the buildings necessary for housing the plant. There is, however, a tendency in some cases to over-elaboration in the lay-out of power stations and the use of auxiliary plant. While this may effect a slight reduction in, say, coal costs, it must react on the total costs because of the heavy capital expenditure per kW of plant installed.

The equipment of power-station boiler-houses has also undergone important developments during the past 16 years. Boilers have increased in size in a manner corresponding to the increase in size of generating plant, and this has led to a greater steam output per square foot of floor space, thus helping to keep the size of the station buildings within reasonable limits.

The generating-plant development has necessarily resulted in increased boiler pressures and steam temperatures. To meet these conditions, the design of boiler fittings and the material used in their manufacture has improved, with the result that previously impossible demands—particularly as regards temperature—can now be met with safety. For example, the new station at Ironbridge is to operate at a steam pressure of 400 lb. per sq. in. and a steam temperature of 800° F. These figures are typical of the power station of to-day.

The increase in the output from individual power stations, and the interconnection of such stations either by joint electrical authorities or in connection with the grid scheme of the Central Electricity Board, has necessitated the redesigning of heavy switchgear. In 1917 most of the heavy power-station switchgear had a rupturing capacity not exceeding 350 000 to 500 000 kVA, whilst for substation work the average capacity called for was in the neighbourhood of 50 000 to 75 000 kVA, the normal high voltages being 6 600 and 11 000 volts. There were, of course, exceptions to these voltages, a certain amount of 33 000-volt and 66 000-volt switchgear being in use.

With the advent of the grid serious consideration had to be given to the question of main switchgear. Investigation of the possible values of the short-circuit currents that could occur showed the necessity for increased rupturing capacity, and in most of the power stations of to-day where the switchgear has been brought up to date the rupturing capacity is from 500 000 to 1 500 000 kVA. In many cases switchgear installed in substations is being replaced on account of the necessity of increasing rupturing capacity. These replacements are, and will still further become, a serious item of expenditure.

The cost of switchgear per kW of plant capacity has naturally increased, until to-day it is probably double what it was in 1917. At that time the cost was about £1 5s. per kW of plant, whereas to-day it is in the neighbourhood of £2 10s. per kW.

The necessity for higher rupturing capacities has led to an entire alteration in the design of switchgear; the older type of switch has had to give way to totally-enclosed switchgear of either the cellular or the ironclad type. Switchgear is becoming practically foolproof and is provided with many devices to safeguard life. Its enclosed design excludes vermin, moisture, and dust, which had each been responsible for serious troubles in earlier types. For the very much higher voltages and rupturing capacities now prevailing, outdoor switchgear is becoming the order of the day; it is particularly exemplified in the grid substations which have been erected in many places.

A notable advance in switchgear has taken place in the design of the oil switch itself. At one time, if a switch failed it was generally merely strengthened in an endeavour to overcome the trouble. Nowadays, however, a much more complete knowledge of what takes place in an oil switch is available, and more scientific designing is possible. In the older designs a jet of oil was forced into the arc path when the oil switch was opened. This method, however, was not altogether a success, as the flexibility of the arc enabled it to move out of the range of the oil jet. Further experiments indicated that it would be better to force the arc into a confined volume of oil, and as a result a device known as the " de-ion stack " is being produced which is, I believe, giving excellent results. The device tends enormously to reduce the arc energy in an oil switch, and to give consistency in operation. Sixteen years ago switchgear was one of the least important items of power-station equipment as far as housing was concerned, but to-day it is probably one of the most difficult and costly items to provide for.

* *Journal I.E.E.*, 1917, vol. 55, p. 46.

The increase in the size of power stations and their greater importance to the country, together with the wider technical knowledge necessary for their operation and maintenance, calls for a more highly skilled engineering staff than in the past. It is pleasing to note that the services of members of power-station staffs are being more adequately recognized to-day than they have ever been before, largely owing to the formation of the Whitley Councils.

Electricity supply authorities, particularly those controlled by the municipalities, are prepared to deal with distribution over much larger supply areas than in the past, and they no longer confine themselves to their own limited municipal boundaries. To-day the unallocated areas are comparatively small, and there is no doubt that, with the assistance of the grid, they will soon be eliminated.

Two outstanding examples of municipal enterprise in dealing with rural development are those undertaken by the Corporations of Norwich and Bedford. The schemes have not yet been in operation sufficiently long to yield reliable results, but they show every prospect of proving satisfactory. The development of these larger areas naturally means that the capital expenditure on distribution is increasing and is becoming a very important point in the capitalization of a supply authority.

The non-industrial demand for electricity is a very progressive side of the business to-day, and it should be fostered wherever opportunity arises. The domestic demand offers an enormous field, probably bigger than that for industrial purposes, and as it is of a less fluctuating nature it is quite as valuable as the industrial load, if not more so. The domestic use of electricity is no longer confined to lighting but is expanding in every direction, particularly in the field of cooking and water heating. The habits of the population seem to be changing, especially as regards cooking, and to-day it is becoming quite the exception where electricity or gas are available, for any cooking to be done by coal. Electricity undoubtedly offers the best medium for providing amenities, and the demand for its use now exists in every class of property.

Assisted wiring schemes and the hire or hire-purchase of apparatus are increasingly assisting in the use of electricity in the cheaper class of house. It is common experience that where new property is being built, there is no difficulty in getting services into practically all the houses. The standard of lighting is steadily increasing among all classes of consumers, but owing to the great improvement in the efficiency of lamps which has been effected in the last 16 years the actual cost of lighting is much less than formerly. In fact, the cost of lighting has been reduced to such an extent that if the new sodium lamp becomes a commercial proposition in reasonable sizes it will behove supply authorities seriously to consider selling lighting services instead of units of electricity.

Another feature of lighting development is the tendency to install floodlighting as a permanent part of the illumination of the larger buildings in our towns. Such installations greatly brighten and beautify the buildings where they are adopted, and they also constitute a useful load for the supply authorities.

Most supply authorities find that in dealing with the non-industrial side of their business it is essential to have a showroom. The majority of these showrooms are exceptionally good, and the work of the Electrical Development Association has been of considerable assistance to many of its members in this respect.

It is pleasing to realize that during the last two or three years when industrial troubles have been so great and many industries have suffered very heavily, electricity supply has been able to make steady and—under the circumstances—satisfactory progress, the economies effected being so great that in the majority of cases the prices charged for electricity are lower than in pre-war times.

The supply of electricity for manufacturing purposes is one of the most important key industries of the times, and we can confidently look forward to its becoming increasingly useful to all sections of the community. As Émile Zola has said: "The day must come when electricity will be for everyone, as the waters of the rivers and the wind of heaven. It should not merely be supplied, but lavished, that men may use it at their will, as the air they breathe."

TEES-SIDE SUB-CENTRE: CHAIRMAN'S ADDRESS

By W. A. GALLON, Associate Member.

(*Address, abridged, delivered at* MIDDLESBROUGH, *17th October*, 1932.)

I propose to deal in this Address with the subject of the electrical theory of matter. Many reasons have contributed to this choice, the chief one being definitely selfish. I am interested in it. Further, the modern theories of matter are electrical, and electrical men have an interest in electricity apart altogether from their own branch. Another reason is that the subject seems to be a common meeting ground for all the sciences: heat, light, chemistry, and strength of materials all seem to be curiously intermingled in it. One might almost say that if the ultimate constitution of matter were absolutely understood, the division of science into its many branches would be unnecessary: there would be only one science—electricity.

If those watertight compartments of elementary science which figure so largely in the curriculum of schools could be co-ordinated—and the present tendency seems to indicate that they eventually will be—the scientific education of youth would be immensely simplified. Education would cease to be an absorption of multitudinous uncorrelated facts and become more a series of exercises in directive reasoning—a much more logical proceeding, and productive of a more highly developed brain.

Let us examine what constitutes electrical engineering. To most of us in this district, it means heavy electrical engineering. We deal with large currents and high voltages. High-speed turbo-alternators, large transformers and motors, transmission lines, cables, etc., form the basis of our daily work. The majority of us belong to the electrical competitive trades, by which I mean that the applications of electricity with which we deal are in competition with other means of producing motive power. A few of us are representative of the non-competitive electrical trades, such as the telegraph and telephone industry, electrochemistry, and the distributing trades.

We all use the common phraseology of electricity. We talk of amperes, volts, watts, ohms, and farads, to which some of us prefix " kilo " or " mega," and others " milli " and " micro." We use these terms very glibly, and we seem to make ourselves intelligible one to another. However, although we thus seem to have established an astounding familiarity with electrical terms, we are no nearer acquaintance with the entity " electricity " than were our illustrious predecessors who gave their names to our units. We seem to resemble in some ways a mathematician who has thoroughly learnt the calculus yet lacks a knowledge of arithmetic. Although he can perform abstruse analytical calculations he is unable to turn them to practical utility, because he does not know the science of numbers. Electrical engineers seem to be in a similar position. We have learnt all about the applications of electricity without knowing at all what electricity may consist of. This seems very illogical, and I consider that it behoves all electrical engineers to study intensively the modern views on electricity and matter in order to consolidate the basis of their scientific training.

Not the least of the benefits which accrue from a more intensive study of the newer electrical theories is the realization of how many uncorrelated facts previously learnt find their true places in a coherent whole. The facts of physics, chemistry, and strength of materials fall into their respective places as portions of one all-embracing universal science—the study of the electron.

We have all read various articles on " the atom " and " the splitting of the atom " and have probably passed them by as being interesting but inutile. At the present time no doubt this is a correct description, but further experiment and research will eventually result in the present methods of production and utilization of energy being superseded. The successful engineer is one who has imagination, who can foresee; and to foresee is to have studied the past and the present. The engineer must study the present activities of the research laboratories if he is not to become in the future the servant of a physico-chemical technical directorate.

Before attempting to indicate where the newer theories of matter make contact with the science of electricity, I shall review the historical development of the theories, and chiefly those of the past 30 years.

Last year was celebrated the centenary of Michael Faraday, whose discovery of electromagnetic induction opened up a field of endeavour which is now called electrical engineering. The celebrations were supported by kindred societies representing the chemical industry —to recall to the minds of chemists that Faraday discovered the organic compound benzene, and electrochemical equivalents, and thus may also be called the father of organic chemistry. Thus 100 years ago chemistry and electricity found a common home in the mind of Faraday, and now chemistry and electricity seem again to be meeting in the minds of many men.

At the time of Faraday, Dalton's law of chemical proportions (1808) was fairly well established. Faraday's introduction of the idea of electrochemical equivalents (1833)—the first numerical link between matter and electricity—was a big step forward. It was followed 20 years later by the valency-bond theory of Frankland.

The first periodic arrangement of the chemical elements, due to Newlands, was received with derision by the learned professors, one of whom suggested that a classification in the order of their initial letters would be an equally suitable arrangement. Yet the work of Newlands was officially recognized 20 years after it was

first published. It was not until Mendeléeff propounded his periodic system, and even then not until he had prophesied all the necessary data for a then undiscovered element, that any acceptance of his theory was obtained from contemporary chemists. A further field of discovery was inaugurated by the researches (1879) of Crookes into the phenomena of the passage of electricity through highly evacuated tubes. Many other investigators of seemingly unrelated lines of discovery followed in the intervening years of the nineteenth century, and it is impossible to enumerate more than isolated instances which appear as landmarks in the march forward. Arrhenius and Stoney are noteworthy, the former for the theory of ionic disassociation and the latter for the naming of the electron.

An important step forward was marked by the discovery, by Lord Rayleigh and Sir William Ramsay, of argon and (later) helium; not only because these were the first instances of a chemical substance which appeared to have no chemical properties, but also because they filled vacant places in the periodic table, and gave form and substance to what had previously been a tenuous and somewhat hypothetical arrangement. About the same time Röntgen discovered X-rays, which were to form an invaluable tool in the hands of later investigators.

Another advance was marked by the researches of Sir J. J. Thomson and E. Wierchert. They independently ascertained that the ratio of charge to mass of a negative ion in a Crookes tube is 1 800 times the ratio of charge to mass in a hydrogen ion. Hence the mass of an electron is 1/1 800 of the mass of a hydrogen atom, i.e. the electron is smaller than what was then the smallest atom.

This brings us to 1900, and the intervening years up to the present time have been fruitful in research and discovery. Research into the atomic structure has proceeded concurrently with research into radio-active substances, with mutual benefit. It is of interest to electrical engineers to remember how much of this research work was accomplished by electrical methods. About this time Planck brought forward his quantum theory, the discontinuous conception of energy gain or loss upon which Bohr later built his theory of atomic structure.

It is difficult to give an account of the more recent discoveries, owing to the immense number of investigators; but to confine ourselves entirely to the one field, the names of Rutherford, Moseley, and Bohr must be mentioned because they contributed such an immense amount to the understanding of the atom. Rutherford, amongst other things, contributed the idea of the atomic nucleus, Moseley the ordinal number arrangement of the elements, and Bohr the dynamic conception of the atom, taking into account the quantum theory, and displacing the "static" atom idea previously prevalent amongst chemists.

Let us now consider the broad outline of the periodic arrangement of the elements, and what it represents. It is now known that there are 92 elements, and they are given atomic numbers ranging from hydrogen (1) to uranium (92). These numbers are additional to the atomic weights, and there is no relation between the atomic number of any element and its atomic weight. The atomic numbers are taken to represent the numbers of electrons circling round the nucleus of the atom, whilst the atomic weight is due to the central nucleus. As all atoms are electrically neutral, the nucleus must consist of a number of positive charges, and the number of positive charges determines the atomic weight of the substance. As an example, neon has an atomic weight of 20 and an atomic number of 10. There are thus 10 planetary electrons, and 20 positive charges in the nucleus. Since there is no resultant charge on the atom there must be 10 negative charges locked up in the central nucleus. The electrons which are rotating around the central nucleus arrange themselves in definite zones; and one can imagine them as being similar to the conventional pictures of the rings of Saturn. As the radius of an orbit increases, the number of electrons which can be accommodated on that orbit also increases, since the circumference is greater. For example, a heavy atom such as gold (atomic number 79) will have 2 electrons in the first orbit, 8 in the second, 18 in the third, 32 in the fourth, 18 in the fifth, and 1 in the sixth. In this atom the first, second, third, and fourth orbits are complete. The fifth is at a stable combination and the sixth contains a very loosely held electron. Taking an element of less atomic number, for instance, copper (atomic number 29), the orbital arrangement is 2, 8, 18, 1. The character of the elements in many respects seems to be entirely due to the arrangement of the planetary electrons, and the striking similarities which are exhibited in the periodic table leave no doubt that the arrangements taken up by the electrons determine the nature of matter.

A general survey of the elements discloses the fact that many of their chemical and physical qualities vary in a periodic manner throughout the table, and these variations are intimately bound up with the electrons in the outermost sphere of the atom. Taking one of the chemical qualities first, the combining weights of the various atoms to form molecules of inorganic compounds are determined by the number of electrons in the outer orbits, and the law which governs the behaviour of the atoms when entering into chemical combination appears to be that each atom endeavours to complete its outer orbit of electrons so as to form a stable ring of 8. For example, 1 atom of sodium, which has 1 electron in its outer orbit, combines with 1 atom of chlorine, which has 7 electrons in its outer orbit, to form 1 molecule of sodium chloride (common salt), with a complete ring of 8 electrons round the molecule. In general, it can be stated that atoms with 1 electron in the outer shell are monovalent, atoms with 2 electrons in the outer shell are divalent, and atoms with 3 electrons in the outer shell are trivalent. This is the electrical theory of valencies.

Other methods of chemical combination exist, chiefly amongst the organic or "covalent" compounds, and the divisions of chemistry as we know them, i.e. metallic, inorganic, and organic, are based on the electrical method which the atoms adopt in combining one with another. Metallic chemistry deals with those atoms which combine to give an electro-positive molecule and thus release free electrons, inorganic chemistry deals with those atoms which combine to give a neutral molecule, and organic chemistry deals with those atoms which combine to give an electro-negative molecule and thus do not release any

free electrons. It is interesting to note that the first group consists of conductors of electricity in the solid state, the second of conductors in the liquid state, while the third are in general insulators.

A physical property of matter which varies in a periodic manner throughout the list of elements is the atomic volume, which gives a measure of the size of the spaces between the atoms, or the "porosity." Peaks of high atomic volume are occupied by sodium, potassium, rubidium, and cæsium, all of which are very active chemically. It thus appears that materials of low density are more chemically active than dense materials. The electron groups of these elements are:—

Sodium	2, 8, 1
Potassium	2, 8, 8, 1
Rubidium	2, 8, 18, 8, 1
Cæsium	2, 8, 18, 18, 8, 1

In each case a completed inner ring of 8 has an outer orbit containing 1 electron.

The melting-points of the elements also vary periodically; the elements with the smallest atomic volumes, and the elements which precede them, have high melting-points. In this class are boron, carbon, silicon, titanium, molybdenum, and chromium. Elements immediately following minimum points on the atomic-volume curve have low melting-points.

Other physical characteristics which show periodic variations are malleability, electrical conductivity, coefficient of expansion, and colour of salts. The last-mentioned property occurs at or near a point of minimum atomic volume, and is exemplified by iron, cobalt, nickel, and copper. Malleable elements occur at or immediately following a maximum point of atomic volume, e.g. beryllium, manganese, and magnesium; or at a minimum point, e.g. zinc, copper, nickel, and iron. Brittle elements occur just before minimum points, e.g. chromium and manganese. Good conductivity occurs in elements lying between elements which are difficult and easy to melt, e.g. copper, between nickel and zinc; silver, between palladium and cadmium; gold, between platinum and mercury. Many chemical properties also vary in a periodic manner throughout the table of elements.

From the point of view of an electrical engineer the electrical conductivity of an element is of great importance. In the table in col. 2 some of the more common elements are arranged in the order of their conductivities.

The metals with the highest conductivities are those which have a shell of 18 electrons with an outer orbit of 1 electron, presumably because when the metal crystallizes in the solid form the ring of 18 electrons is broken into, to release free electrons.

Let us now deal with the mechanism of conduction of electricity. It is assumed that the metal consists of a number of positive ions—atoms which have lost negative electrons—arranged in the crystal lattice, the electrons they have lost being free to move about among the ions. Inside the metal the electrons will behave much as a gas is assumed to behave in a closed chamber. If the electrons are caused to move in a stream through the metal, collisions with the positive ions in the crystal lattice will take place and the direction of motion of any one electron will be changed, i.e. a resistance to the electron movement will manifest itself. Also, since collision of an electron with an ion means that the electron must give up some of its kinetic energy to the ion, when a stream of electrons is flowing the average kinetic energy of the ions will increase. An increase of kinetic energy means an increase in temperature, so that a steady stream of electrons will raise the temperature of the metal through which it flows. This, of course, is one of the unfortunate facts with which electrical engineers have to contend, and it is of interest to note that anything in the metal which disturbs in any way the regular arrangement of the crystal lattice affects in a marked degree the conductivity. This accounts for the much higher resistance of metallic conductors made of impure as compared with pure metal.

The brief review which I have given of the properties of materials in relation to their places in the periodic table seems to give rather too much prominence to the Rutherford-Bohr atom. The idea of an electron conveyed by my remarks may resemble too much a small ball travelling round an orbit and probably revolving. This idea of an electron as a hard substance is, of course, out of date and incorrect, and the newer theory of a wave motion should be substituted. As, however, I am unable to visualize an atmosphere of wave motion, and as most engineers have pictorial minds, the older idea is more understandable, and it satisfies the requirements of the physical properties quite satisfactorily.

Element	Specific resistance	Electron distribution
	ohms per cm cube	
Silver	1·468	2, 8, 18, 18, 1
Copper	1·561	2, 8, 18, 1
Gold	2·197	2, 8, 18, 32, 18, 1
Aluminium.. ..	2·665	2, 8, 3
Magnesium.. ..	4·355	2, 8, 2
Zinc	5·751	2, 8, 18, 2
Iron	9·065	2, 8, 14, 2
Cadmium	10·023	2, 8, 18, 14, 2
Palladium	10·219	2, 8, 18, 18, 2
Platinum	10·917	2, 8, 18, 18
Nickel	12·323	2, 8, 16, 2
Tin	13·048	2, 8, 18, 18, 4
Thallium	17·633	2, 8, 18, 32, 18, 3
Lead	20·38	2, 8, 18, 32, 18, 4
Mercury	94·07	2, 8, 18, 32, 18, 2

I have rigorously excluded dimensions and equations from this Address and have confined myself entirely to a general treatment. There is, however, one constant which gives some idea of the magnitudes involved: 1 ampere = 8·79 trillion electrons per sec.

I have left much unsaid and have omitted to consider many difficulties and contradictory points in the complete application of the theory. Nevertheless, anyone who reads the abundant literature of the subject will find therein a mine of information and a topic of absorbing interest.

DUNDEE SUB-CENTRE: CHAIRMAN'S ADDRESS

By I. SCLAR, Associate Member.

"'SERVICE' IN THE ELECTRICAL INDUSTRY."

(*Address, abridged, delivered at* DUNDEE, 13*th October*, 1932.)

The scope of this Address is very wide, as "service" in the electrical industry covers a large field. Modern civilization is centred round "service" of some description. We are all servants in some way; we serve someone, our machines serve us, and both we ourselves and our machines are servants of the public.

As civilization advances, service becomes more and more important. If service does not progress with the advance of civilization, then civilization will get out of gear. The electrical industry has advanced rapidly within the last 50 years, and the purpose of this Address is to examine in an unprejudiced way the question whether service is being given full consideration. Electricity itself is a vital service, and though every industry gives a public service the electrical industry provides a greater public service than most. This means that more people are dependent on this industry than on others.

What do we mean by "service," in the broad sense in which the word is used to-day? I would define it as the act or series of actions which, when performed properly, result in the maximum ultimate benefit to the maximum number of people.

One might sit back contentedly and say, "See what we have done in 50 years, see how we have advanced; we must have given the service to have produced this result." I maintain that, because the industry is comparatively young and because of the rapid advance in practically all its sections, we have not paid sufficient attention to service, and that if we had given it proper attention the industry would have advanced still further.

Prejudice plays a very important part in the advance or retardation of progress, more often in the latter. We all suffer from prejudices which past experience has ingrained in us. Quite often prejudices keep us from actions which have been proved not to be beneficial, even though strong evidence may be advanced in their favour, and quite often we are right in adhering to such prejudices. However, more often than not these prejudices prevent us from doing things in a better, easier, and more economical way. Whenever we do a piece of work we ought to ask ourselves whether we are doing it in such a way as to give the maximum ultimate benefit to the maximum number of people, i.e. in the "service" way. We are inclined to follow precedent far too much and to do things as they have always been done before, without giving the matter proper consideration.

I have already mentioned that the advance in the electrical industry within the last 50 years has been great. The probability is that in the first 10 years of this period progress was slow, in the next 10 a little greater, and as the years went on the rate of progress increased. Within the last 10 years the progress has been phenomenal, and it would be difficult to prophesy what advance may take place in the next 10 years. Because of the rapid progress we are making in the uses of electricity and the daily improvement in the design and efficiency of apparatus and plant, we tend to build too much for the future. Our designs and installations are of too permanent a nature; they are too strong and rigid, and therefore too expensive in first cost. Engineering products should be designed from a utility and service point of view. It is every engineer's duty to spend the minimum consistent with the service expected. We are inclined to design apparatus, plant, or works, to last too long, in view of the present rapid rate of change of design. The plant should be planned to give a reasonable factor of safety, taking into consideration the duty for which it is intended. We must learn to judge as accurately as possible what the factor of safety should be, as too high a factor of safety is unnecessary and expensive. At the present moment we have innumerable factories fitted with obsolete plant whose first cost has been high, the plant and machinery having been designed with an excessive factor of safety. In modern industry manufacturing processes change rapidly, and machinery becomes obsolete long before it wears out. Industry must be flexible, ready to change and modify itself at short notice. Expensive plants mean excessive capital charges, and again one grudges to scrap an installation which was expensive in first cost. In my opinion manufacturing plant should be designed to last 7 to 10 years, so that when more efficient and modern apparatus is available it can be installed, thus keeping the manufacturer in a competitive position.

I am not advocating a policy of shoddy apparatus or cheese-paring in the design of an installation. By all means spend the maximum possible sum, provided that the money spent will provide apparatus which has the maximum operative efficiency at the time it is built, is up to date, and is able to give the maximum service. The purpose of designing a piece of machinery or an installation is to obtain a definite service at the minimum cost. If one has more money to spend, it can be spent in purchasing further apparatus to give further service.

I have in mind a particular case which I met with a few years ago. A client wished to discard a battery and private plant which was supplying energy for several hundred lights and a certain amount of power. A consulting engineer was asked to draw up a specification for the equipment necessary to take in the public supply to feed the existing load, and ultimately, if funds per-

mitted, to extend the electrical service so as to give supplies for electric heating and cooking in the works canteen. The installation was very well specified by the consultant, except for the fact that, considering the duty required, it was much too elaborate. The result was that all the available money was spent in the initial change-over, and none was left to pay for the extra services. The client has therefore to go without the extra services, the supply company without the revenue from the extra units which might have been used, and the manufacturer of the extra apparatus without the orders. The argument that as long as all the money was spent everyone got their share at the time, is fundamentally wrong. Extra money spent which does not give extra service, though giving the supplier extra profit at the time, does not ultimately produce the maximum result for the maximum number of people.

Every person who designs—and we are all designers in some way—must first of all bear in mind the service the apparatus in question is to give, and then go on to design the apparatus in such a way as to produce this result. He must then examine his design and cut out any part which does not tend to give a better ultimate service, keeping in mind that a factor of safety is required. With present-day methods of mass production and knowledge of strengths of materials, no article need be shoddy, even though it may be cheap. The greatest industries have not been built up in producing high-class apparatus for a few selected and lucky people, but in catering for the masses by producing an article of reasonable durability to give reasonable service at a reasonable price.

The electrical industry is hampered by many kinds of regulations and many prejudices. A large number of these regulations are based on the results given by apparatus on the market 10 to 15 years ago. Electrical apparatus is always improving and becoming safer, and the regulations which might have been a protection for apparatus designed 10 years ago are unnecessary for the apparatus of to-day, with its better and safer design. Any unnecessary regulation which increases the cost of apparatus or installation, and which does not mean extra service to the man who pays, ultimately retards progress. Reliability and continuity of operation are vital considerations, but very often these are bought at too high a price. There are certain spheres where continuity must be obtained irrespective of cost, but these are more often isolated cases. When more is spent on an article than is absolutely necessary for a particular service, and such extra cost goes to provide greater reliability, the extra cost should be regarded in the light of insurance. Much of the switchgear and control apparatus installed is not called upon to perform the functions for which it is intended. Much of this control apparatus is unnecessary, and instead of being an extra insurance and protection it often proves an extra complication and source of weakness.

The national grid scheme has given the industry a wonderful advertisement and made the public think electrically. This country is suffering from industrial depression, and yet the number of units generated and sold is increasing. The domestic load is growing, and if industry had been in its normal state there would have been a very much larger increase in the consumption of electricity. Every day new uses are being found for electricity, and the consumption is bound to increase.

The supply authority enjoys a virtual monopoly in its particular distributing area, and it therefore does not suffer from competition with other companies in the same line of business. This monopoly restricts the freedom of the supply company to pick and choose its customers, but once it has made a customer it is more certain than in most other industries of retaining that customer's business. When a consumer takes current from a supply company he usually makes himself dependent on the company for all future supplies of the product. Every consumer connected to the supply mains is a potential customer for more and more of the product sold by the supply authority.

How are we to get the consumer to buy more of our product? The way lies through the education of the consumer in the uses of electricity. While the supply industry may be quite up to date in technical matters, it is lacking in the art of salesmanship. More is now being done to sell electricity, but still the efforts are feeble. A comparison between the expenditure on advertising and selling of the supply industry, with its vast capital and steady and increasing turnover, and the advertising expenditure of the motor-car and wireless industries, reveals how very backward we are in this direction. I maintain that in no other industry could intensive collective advertising be applied with better hopes of success. The allocations and the results for each district can be ascertained without difficulty. The electrical industry is really afraid to advertise. In many industries advertising brings more business, but it also brings increased overhead charges, though the overhead cost per article may decline. In the electrical supply industry increased sales of units do not increase the overhead expenses in as large a proportion, and the result is a much greater reduction in overhead charges per unit than in most other industries.

I often think that those who supply electricity do not realize the value of the product they have to sell, they do not seem to realize the service it can give; in fact, they lack confidence in the goods they are selling. Much of the talk about the high running costs of electrical apparatus emanates from electrical engineers. Although the running costs of electrical appliances are not always as low as those of apparatus worked by gas or other fuels, we must appreciate the value of the flexibility, convenience, and ease of control—in fact, the better service—given by electrically-operated plant. The supply engineer does not sell "units" but "service," and often extra service; and for extra service a higher price is justified.

I have recently built a house, and in order to get first-hand experience of electrical and alternative methods I have installed coal-fired cookers, coal fires for rooms, a coal-fired domestic hot-water system, and even a certain amount of coal-fired central heating, in addition to my electrical equipment. The coal-fired apparatus is of the very latest pattern. The equipment makes it possible to work the house by electricity, by coal, or by a combination of both. The experience of everybody concerned in the house is that definitely consistent

results can be obtained from the electrical equipment, while a good deal of guesswork is necessary to operate the coal-fired apparatus. The latter demands more study and nursing; sometimes the results are good, but they are more often bad when compared with those obtained from the electrical installation. I add the last clause because it is only after one has experienced the electrical way that one can realize the high standard of service to which it is possible to attain. The current charge for my house averages $1\frac{1}{2}$d. per unit, and my experience so far shows that at this rate it is possible to get very good service economically.

This experience has made me more electrically enthusiastic, has imbued a new spirit into my sales talk, and has brought and will bring extra business to the firm with which I am associated. The electrical supply industry needs good salesmen, and the best way to train them is to make them live in houses which are operated chiefly by electricity. I suggest that every salesman in the supply industry should be given some inducement to live electrically.

The fact that the price of the unit is dependent upon distribution costs means that we must concentrate on this item in order to keep the price of the unit down. The distribution system should be as simple as possible, free from unnecessary expensive control and protective gear. Every item of plant and apparatus in a distribution network should be carefully scrutinized and its necessity questioned well before it is installed. In certain cases underground cables and services may be less costly, but as a rule I think overhead services and distribution will be cheaper. When overhead services are used the copper should be kept to a minimum consistent with a reasonable voltage-drop. Provision for future extensions should not play so important a part in design as it does at present, for lighter copper conductors can easily be replaced by heavier ones, and very often the lighter copper can be used again on other sections. This is not so easily done with underground cable services, and therefore a greater margin has to be allowed for future extensions, with the result that first costs are higher and capital lies dormant longer. The aim should be to give an adequate service for the minimum expenditure of capital, so that the return of the capital is quicker, thus leaving a margin to accumulate for financing future extensions. Overhead distribution is certainly more unsightly than underground, but electrical engineers should not pay too much heed to this. We must remember that we are giving a public service, and that the result of cheap and abundant electricity will be to the national good. We hear a lot about beautiful villages and country roads being made unsightly by overhead lines, but we do not hear of the boon we bring to villages and isolated country-sides in the way of better-lighted, cleaner, and healthier homes.

A friend recently showed me a bill from a gas company across which was franked the words: "We want you to get the most out of every cubic foot of gas we sell you, and we are always prepared to tell you how." This is the spirit we want in the electrical industry. We must see that the consumer is getting the maximum service from what he uses and pays for. Periodic calls at the consumer's premises might be made by a representative of the supply undertaking to see that the most efficient type of apparatus is being used. Visits like these come better from the supply side than from the contractor, particularly if the supply company does not sell new apparatus, as their advice is then considered impartial.

When a supply is asked for, the undertaking concerned often raises the question of a guarantee. While a guarantee to give some definite return for the capital outlay is only reasonable, this guarantee should be as moderate as possible, seeing that the supply company—like any other commercial concern—is entitled to take some business risk. When a firm takes up a new line of goods it has no guarantee that it will get people to buy, but by giving service it expects to be able to sell the goods. Before they will take a cable along a street many supply companies insist upon having a definite assurance that a certain number of consumers will take the service. Although this may be quite right, a business risk might be taken. Which is the right way, to make the service available so that it can be taken advantage of when required, or to wait until it is demanded? If every commercial firm adopted an attitude of waiting until a service was asked from it, progressive business would be at a standstill. The supply authority should also not forget to consider that the tendency is towards increased consumption, and consequently the risk involved is not great. In the case of large bulk consumers where an immediate increase of plant is required the case for adequate guarantee is stronger; but for smaller domestic consumers there is a greater spread-over of the risk and less danger of loss of revenue due to reduced consumption. In this connection the use of flexible systems of distribution involving the minimum initial capital expenditure would certainly help matters.

Should supply companies have wiring regulations of their own? Personally I cannot see any reason why they should, as wiring which is satisfactory on a 250-volt supply in Glasgow, for example, should also be satisfactory on the same voltage at Edinburgh. If regulations must be adhered to, let the authorities adopt the I.E.E. Wiring Regulations, which are the outcome of the deliberations of all sections of the industry. We must remember that though regulations may ensure a certain amount of safety in the original installation, the present methods of distributing electrical apparatus allow of very little control over the consumer, who may buy all kinds of apparatus, wire them as he wishes, and connect them to any part of the installation, despite the possibility that the latter may not be designed to supply them. One unsafe flexible cable connected to a portable apparatus can be a source of more danger than all the rest of the installation.

I shall now deal with the manufacturing side of the industry. The first and important fact which manufacturers must realize is that electricity is totally different from gas and other sources of power to which we have been accustomed, and that a piece of apparatus designed for operation by electricity should not be a copy of the corresponding apparatus suitable for use with the older forms of power. Manufacturers still cling to the idea of making electrical fires like coal fires, though the coal fire is what we are trying to supersede.

Electric cookers are copies of gas cookers, and these gas cookers developed from copies of the coal ranges they had superseded. There is frequently very little reason for the shape and proportions of domestic electrical appliances. Apparatus must first be useful, efficient, and economical—and then artistic: it can become beautiful to the eye if it is useful. It is possible for mass-production apparatus to be cheap and yet not shoddy, as mass production needs accuracy for its successful operation, and accuracy brings reliable finish. The other day I was shown a 2-kW radiator selling at 17s. 6d., and I am sure that the finish of this was no worse than that of a similar radiator selling at 3 times this price 3 or 4 years ago. To make the same profit we have to sell many times the number of articles we sold before, but the low price makes them easier to sell. The man who would then only have bought one radiator and have carried it about from room to room, will now buy a radiator for each room, with the result that he will use it much more often: also he will not grudge buying another radiator in a short time when something better and more modern is produced. I do not say that we should cease to manufacture the more expensive article, for which there is always a demand; there is no doubt, however, that the best value is always to be found in the mass-produced article. When apparatus is made too expensive it cannot be changed and improved so often, and progress is retarded in consequence. The characteristics which a manufacturer should aim at achieving are lightness and compactness. A heavy clumsy article is always more expensive to make, and with modern materials and proper attention to design we can get strength without weight. Too many designs and sizes of similar articles are now being made by the same firm, and identically similar articles are being turned out by many firms. Electrical manufacturers do not concentrate sufficiently on a definite and reasonable number of lines. Too many firms want to manufacture every kind of electrical apparatus, fearing that they may miss something by omitting to produce any one particular line.

Though a few years ago we reduced the number of sizes of wires in use, we still have too many sizes, grades, and classes of cables. It cannot be conducive to the best service to have one manufacturer manufacturing cables from the smallest and lightest flexible to heavy super-tension cable. There are many cables of different grades and types, all to perform the same job. Even the standard range of the cable makers is not enough, as cables have often to be manufactured to meet the special specifications of engineers. Certainly the conditions under which we convey current are not always the same, but they are much more similar than the wide range of cables would make us believe. A little more standardization here would bring the prices of cables down, and cheap services and installations are dependent on cheaper cables. I was recently asked whether cheaper house-wiring cables would be beneficial to contractors, who are the biggest users of this class of cable. It was stated that if the price were lower more business would require to be done to make the same profit. My reply was that, if cables were cheaper, for a given sum I should be able to induce a client to install more switches and outlet points and thus give better service, in which the supply and manufacturing industries would also share.

We also have too many different speeds for motors and generators. This is a high-speed age, and the higher the speed the lighter, more compact, and more economical is the machine. In the past we have been accustomed to, and prejudiced in favour of, low speeds, but we must remember that years ago we did not know so much about the strength of materials as we do to-day. The high-speed machine of to-day can be made just as reliable as the slower and heavier machine of yesterday. There is a tendency towards individual drives on machines, due to the fact that machines have to be driven individually if they are to meet the flexibility requirements of modern manufacture. These machines are often gear-driven, and with the development of modern gears we can just as easily use a high-speed machine as a slow one. I also think we have too wide a range of horse-powers; I favour a smaller range, but making more use of the $\frac{1}{2}$-hour rating. Very few machines work at full load all the time. The cheaper we can make an electrically-driven machine, the easier it will be for the manufacturer to scrap it in due course for something better. In catering for the public demand the manufacturing electrical engineer must not be tempted to place something on the market which from an engineering point of view is unsafe and liable to misuse. An instance of this is the plugs which have recently been introduced to take 3 or 4 different connections, even though the main connection is designed to take only 5 or 10 amperes. An accessory like this can be very useful and convenient in skilled hands, but in unskilled hands it is a veritable source of danger.

Specifications for contracts should be drawn up as clearly as possible, and should state definitely what is required, so that the minimum is left to the imagination of the estimating firm. Every specification should be accompanied by a detailed schedule of quantities; the computing of the quantities is the responsibility of the engineer, and should not be left to the contractor. Further, the schedule is a basis on which to adjust additions and deductions, as nearly every contract is modified during its progress. A schedule of quantities should cover every item which is variable, so that a rate is obtained for any adjustments. For instance, the running of a paper underground cable, part underground and part overhead, might be divided into (*a*) supply of the cable, (*b*) necessary digging, (*c*) laying of the cable underground, (*d*) fixing of the cable overhead, and (*e*) the supplying and connecting of the necessary sealing or joint boxes at ends and intermediate points. Two charges which may prove to be variable should never be grouped under one item. It is only by a very accurate schedule of quantities that close pricing will be achieved and guesswork eliminated.

When specifications are being drawn up the engineer should endeavour to make himself acquainted with standard materials, and should make use of these as much as possible. There are good-quality standard articles on the market suitable for 90 per cent of jobs, and they give very good service. With regard to control gear, particularly for domestic and other non-industrial use, rigid specifications are not necessary, for

the majority of the gear is very seldom used, being operated more as main and isolating switches. Only in the best-quality work—for museums, churches, and similar buildings erected for posterity—are the most expensive materials necessary. Expensive material does not necessarily mean the greatest factor of safety, as much depends on the way the installation is carried out. Medium-priced material carefully installed will prove better and safer than expensive material carelessly installed.

It must be remembered that in the electrical world changes are now going on faster than ever, and what was considered 10 or 15 years ago to be practically permanent has been proved to be otherwise. This fact is particularly important from the investment point of view. We must get as quick a return as possible on the capital invested, and the way to do this is by installations with a reasonable factor of safety but without elaborations. We must learn to discriminate between what gives extra service and what does not. Extra motors and machines, extra outlet points, and extra useful apparatus give extra service and bring a return on the extra capital invested, but unnecessary and too-expensive switchgear, fuse-boards, cables, and accessories do not give extra service. We must remember that our aim is to get the current to definite points, that no service is really given until the current is available at those points, and that the advantages of the service only begins when the current is used. We should therefore make it our aim to get the current to the point at which it is going to be used, as economically as possible with a reasonable factor of safety.

To sum up, we in the electrical industry are expected to give service, and the better the service we give the better it will be for the public good and for our own individual reward.

SHEFFIELD SUB-CENTRE: CHAIRMAN'S ADDRESS

By L. H. Crowther, Member.

(*Address, abridged, delivered at* Sheffield, 19*th October*, 1932.)

In selecting a subject for my Address various topics suggested themselves to me, each sufficiently wide in scope to form an address in itself. I might for instance have given a dissertation on that modern panacea for industrial evils, rationalization. However, rather than labour any one subject I propose to deal in a general way with the modern trend of electrical engineering, outlining some of the changes and improvements which have been effected in electrical apparatus and plant during recent years, mainly as a result of discoveries made by research workers in all parts of the world.

Uses of Alloy Steels.

The use of nickel-, chromium-, and molybdenum-bearing alloys, for instance, has had a tremendous effect upon the electrical industry, the great strength and toughness of nickel-alloy steel being now almost universally utilized in providing shafts for traction motors and turbo-generators, where excessive fluctuating stresses are involved. Again, it was found by Elmen that after special heat treatment a commercial alloy containing approximately 78 per cent nickel and 21 per cent iron had a greater magnetic permeability than pure iron and silicon-iron alloys. Variations in the nickel content involved variations in flux density, hysteresis loss, and electrical resistance, and by choosing the correct proportion of nickel various combinations of resistivity and permeability were obtained. One of the best-known uses of alloys of this type is for continuous loading of submarine telegraph cables and telephone transmission circuits; in the range of magnetic field strength encountered in such cables the high permeability of these alloys as compared with iron enables the carrying capacity to be considerably increased, and thus great economies in operating costs can be effected.

One of the advantages of the new alloy cores is their smaller size and weight, and this has led to a radical departure in the design of small low-frequency transformers for wireless work and also for the many relays used in telephone equipment. The reduction in volume to which they give rise is approximately two-thirds of that required in a silicon-iron-cored transformer, and is obtained without loss of efficiency. This feature is especially valuable in connection with portable receiving sets, aeroplane equipments, etc., where weight must be reduced to a minimum. A new type of current transformer suitable for all applications, with secondary loadings up to 50 VA at any power factor and at frequencies varying from 25 to 133 cycles per sec. on voltages up to 6 600 volts, has recently been introduced. Greater accuracy is obtained by using a ferro-nickel instead of a silicon-steel alloy for the core of this transformer, which represents a considerable saving in weight. Moreover the transformer is strong enough mechanically to withstand short-circuit currents up to 70 times the normal primary rating.

It has been found that nickel-iron alloys containing between 25 and 30 per cent nickel, and also cast iron containing 10 per cent nickel and a certain amount of manganese, are non-magnetic, and such materials have proved particularly valuable for avoiding hysteresis and eddy-current losses in certain types of electrical machinery and apparatus, e.g. busbar chambers, high-frequency furnace structures, alternator end-rings, and resistance grids. The electrical resistance of these alloys is higher than that of iron, while their permeability is as low as

that of brass. In the design of rheostats this feature, together with the low temperature-coefficient, permits maximum capacity to be concentrated in minimum bulk, a point which has been appreciated by tramway and railway engineers.

Other uses to which the nickel-bearing alloys have been successfully put are in the manufacture of alkaline storage batteries, electric-furnace and radiator heating elements, furnace hearths, and the making of glass-to-metal joints in lamps and wireless valves (where a 48 to 50 per cent nickel alloy has a coefficient of expansion nearly equal to that of lead or soda glass), thus providing a comparatively cheap substitute for platinum. I would refer also to the revolution which has been brought about in the manufacture of permanent magnets by the discovery of cobalt steels, and the great part which stainless, heat-resisting, and corrosion-resisting steels have played in the development of the engineering industry. One of the most recent instances of the latter is in the employment of this steel in connection with the grid transmission-line pylons, which should increase their useful life and reduce maintenance costs.

Direct-Current Transmission.

It has been truly said that science, together with the industries based upon its application, stands perpetually on the brink of a precipice. There is always the possibility that some new discovery may upset the whole basis of established ideas. Almost every decade of the past hundred years shows revolutionary progress compared with the one that preceded it. Fortunately there is always a big time-lag between the advent of a new principle, or a new application of an old one, and the realization of its full possibilities. A striking illustration of this is the recent changes brought about by the application of the thermionic valve to the problems of transformation, rectification, and frequency-changing, and I propose to deal in some detail with the probable effect of this development upon the future transmission of power over long distances. In my opinion the thermionic rectifier will supersede the present rotary methods of rectification and frequency-changing, and will be used for supplying high-tension direct current to transmission lines. The present generation of students will probably live to see important changes in the technique of power transmission consequent upon the gradual substitution of direct current for alternating current.

Practically all the troubles connected with a.c. systems arise from the a.c. transmission lines. Alternating current is easily generated and is quite suitable for utilization purposes, but it would probably never have been used as a medium for power transmission had it not been for the impossibility of converting large amounts of high-voltage energy from alternating current to direct current, and vice versa. However, the advent of the 3-electrode mercury-vapour valve or "thyratron" (a development of the vacuum valve by the General Electric Co. of America), and the successful application of grid control to mercury-arc rectifiers, have recently made it possible both to rectify alternating current and to transform direct current into alternating current of any desired frequency, with a high degree of efficiency; and, moreover, the converting plant is static. Thus the one principal advantage of a.c. transmission has disappeared, while its many disadvantages still remain. It would seem, therefore, that the future lies with a.c. generation, conversion to direct current for long-distance transmission and interconnection, and inversion to alternating current again for local distribution.

Before enumerating the immense advantages of the proposed new method, let us look at a few of the problems associated with the present 3-phase a.c. transmission system. First, the cost of a transmission line largely depends upon the amount of insulation which has to be provided, and this in turn is determined by the maximum voltage to earth. For an a.c. line with earthed neutral this will be approximately 80 per cent of the R.M.S. voltage between lines, as against 50 per cent for direct current, assuming the mid-point to be earthed in the latter case. The capacitance of an a.c. line, especially if underground cables are used, causes a large leading reactive current to flow constantly, and at low loads there is always the possibility of a dangerous rise in voltage. The maximum amount of power which can be transmitted over an a.c. line is largely dependent upon the inductive drop and the power factor, and dielectric losses in the insulation of a high voltage a.c. cable impose a very definite limit in cable design. Lastly, there is the cost of the lines themselves, a very serious matter in these days.

If d.c. transmission were adopted all generators could normally be operated at practically unity power factor and could be designed for the voltage or frequency which would give the cheapest, most reliable, and most efficient operation. This point is of particular interest in connection with traction schemes, as it might lead to the supply being generated at a different frequency from that utilized at the receiving end for motors. Networks with different frequencies could quite easily be interconnected without the use of rotary frequency-changers. Important and money-saving modifications in the design of generators would be possible; high-voltage oil circuit-breakers of large rupturing capacity would not be required, as owing to the "one-way" nature of the thyratron the amount of current flowing in the event of a short-circuit would be restricted. The problem of the control of the flow of wattless energy, the difficulties connected with frequency-changing, and the necessity for providing transformers designed for tap-changing under load, would disappear. The cost of transmission lines would be substantially reduced; it is shown in most of the textbooks that for a given maximum voltage to earth and the same loss in the line in each case, assuming unity power factor for the a.c. line, twice as much copper is required to transmit the same amount of power by alternating current as by direct current. The losses in the dielectric and in the sheath or armouring of an a.c. cable have no counterpart in a d.c. cable, which means a cheaper cable for a given service and the possibility in certain cases of using underground cables instead of overhead lines, with consequent greater freedom from lightning disturbances In the *Electrical World* it was recently pointed out* that although it would be possible to make use of present

* *Electrical World*, 1931, vol. 97, p. 488.

conductors for d.c. transmission and even to transmi up to 50 per cent more power through existing underground a.c. cables than they carry at present, a great field would be opened up for experimental research. The importance of the resistance of insulators may overshadow that of their electrostatic capacitance for d.c. work. The influence of high-voltage d.c. transmission on cable design would also be large. In the article referred to it is suggested that single-conductor cables would probably be used. In the light of these developments the recent decision to adopt a.c. transmission universally in this country may perhaps appear a little premature. The development of this form of electronic valve, which at the present time is capable of rectifying and inverting power up to approximately 9 000 kW at 30 000 volts, means that it is happily only a question of time before the a.c. transmission network will be a thing of the past.

Electric Welding.

Another phase of electrical engineering which has made rapid strides during recent years is the use of metallic arc-welding in the manufacture of welded structures to replace iron and steel castings. Castings were and are widely used in the electrical industry as the basis on which to build the majority of electrical switchgear and plant. Many of these are now more usefully replaced by a structure, often dissimilar in appearance, but fulfilling the same principles, of standard steel plate and sections built into the required form by welding. The justification for this innovation is principally an economic one; it is the considerably reduced cost of these fabricated structures compared with similar iron castings which accounts for the rapid growth of this form of manufacture. A paper by L. Miller, read before the Manchester Association of Engineers on the 8th January, 1932, states that the saving in cost—exclusive of patterns, machining, and finishing—of fabricated steel over iron castings varied from 20 to 66 per cent in 14 instances of fairly representative types of castings. The additional saving represented by the cost of the pattern is often a large proportion of the total cost. For instance, as regards the larger castings only a few, and frequently only one, will be made from one pattern; hence the cost of the pattern (which is usually high) has to be borne by one or two castings. An early application of welding in the electrical industry was in the manufacture of transformer and oil-switch tanks, and welded flameproof tanks are now manufactured to stand a working pressure of 350 lb. per sq. in. and a test pressure of 600 lb. per sq. in. Modern switchgear, which is becoming more and more complicated and diverse in type and which is often called upon to deal with very heavy loads, affords great scope to the expert welder, the result being a decreased production cost and an increased factor of safety. In the manufacture of motors there is a useful field of possibility for the application of welding, but it is not as yet so widely used by manufacturers as would be expected. Bedplates for all types of motors and generators, built up from plate and standard sections, are cheaply manufactured and can be made to present a neat, finished appearance. A fair degree of skill is necessary, as much of the work is frequently too large to turn, hence many joints have to be welded in a vertical position. A good deal of the work, such as long, straight, or circular seams having right angles or flat butt joints, is suitable for automatic welding, but unless many of the same size and type of product are being manufactured the time gained by the high speed of welding is offset by that taken in setting up the apparatus. As a nation we are naturally conservative in the adoption of any change from what is considered to be standard practice, but I believe that the utility and economical advantages of this application of welding should be taken advantage of, particularly during the present trade depression.

Closely allied to the use of electricity for arc welding is the method known as resistance welding, where the two pieces of metal to be welded are clamped together, heated by the passage of a large low-voltage alternating current (owing to the resistance at the point of contact the two surfaces rapidly attain welding temperature), and then subjected to mechanical pressure. Present-day applications of this method are to be seen in rivet heating, and butt- and spot-welding machines.

Electric Heating.

An important line of progress in the electrical world is the increasing use of electricity as a source of heat for a wide variety of industrial purposes. As a reliable, economical, and easily-controlled heating medium, electricity is now generally recognized to be superior to other forms of fuel. The fact that the heat equivalent of a unit of electricity is an unalterable physical quantity greatly simplifies both the design and the operation of heat-treatment plant. Moreover, if electric heating is adopted the temperature can be held constant for any length of time by thermostatic control, thus enabling results to be repeated with absolute certainty. Since with an electric resistance furnace there is no restriction as to the rating or location of the heating elements, provided, of course, that the designer knows his job, there is no condition of rate of heating or point of application of heat which cannot be met. Another advantage is that throughout the life of the electric furnace the original conditions of heating are maintained, which is far from the case with gas- or oil-fired furnaces. There are also the factors of cleanliness and satisfactory working conditions, which are none the less real because a definite financial value cannot be assigned to them. In furnaces of the combustion type, whether heated by gas, oil, or solid fuel, accurate temperature control is complicated by the fact that the combustion temperature is considerably in excess of that required in the heating chamber, and the necessary reduction involves not only high thermal losses but makes it difficult to maintain uniformity. Variation in the calorific value of the fuel, and climatic changes causing fluctuations in chimney-stack pull, tend to produce further inequalities in temperature. In addition, it is almost impossible to prevent the products of combustion from coming in contact with the work. The cleanliness of electric heating and its freedom from products of combustion invariably lead to an improvement in the quality of the work so treated, and although the cost of electricity per B.Th.U. is higher than that of coal or gas, the whole of

the energy paid for is used effectively in heating the charge. Owing to the absence of fuel storage and handling charges, the labour costs are considerably reduced. In a recent issue of *World Power** mention is made of the steadily increasing use of the electrically-heated annealing furnace in the U.S.A., particularly in connection with the automobile industry, the reduction in the number of rejects, and the greater ease of machining, often paying the entire power bill. Tests on a gas-fired furnace of the most modern type for motor-car crank-shaft annealing revealed a temperature variation in the charge of 25 to 55 deg. C., whilst the pit-type electric furnace gives a control of $\pm$ 4 deg. C. Electric bogie hearth furnaces have been built recently up to 65 ft. inside length and 3 000 kW installed capacity.

One of the first applications of electric heating in industrial works was for steel melting, the electric arc being employed as the heat generator, and many arc furnaces are now in use producing high-class alloy steels for tools and light castings. More recently, however, the core-less induction type has been introduced, generating heat in the steel itself by means of powerful eddy currents induced in it by a high-frequency alternating current passing through a special water-cooled coil surrounding the charge. Owing to the entire absence of gases in the fuel used, the various impurities present in the older types of furnace are effectively excluded, with the result that new grades of steel having greatly improved characteristics are now being made. Owing to the high efficiency of this type of furnace the consumption per ton of steel melted is remarkably small, and given an improvement in trade conditions there will be great scope for the electrical industry and supply authorities in providing the necessary plant and energy.

Static Condensers.

The extensive use of alternating current during recent years has led to the application of the static condenser to the improvement of power factor. Whether energy is purchased on a simple kWh basis or supplied from a private generating station, the installation of condensers serves a useful purpose in reducing the current loading of generating plant, cables, transformers, and switchgear, thus possibly avoiding costly expenditure on extensions or replacements. When, as is more usual, particularly with supplies taken in bulk, a two-part tariff is imposed, made up of a fixed maximum-demand charge and a kWh charge, where the fixed charge is based upon a kVA demand a saving can often be achieved by installing condensers of suitable capacity. Where the initial power factor is at all low, say below 0·7, the condenser will effect a reduction in kVA which with most tariffs will represent a return of from 40 to 100 per cent on the capital cost of the condenser installation. Obviously the cost of improving the power factor from 0·6 to 0·8 will be considerably less than that of raising it from 0·8 to 0·9, but in certain special cases improvement to just below unity has proved an economical proposition.

About 11 years ago I was interested in the installation of some 1 500 kVA of static condensers for the purpose of correcting the power factor of an electrically-driven rolling mill; in this case the saving resulting from reduced kVA charges alone was sufficient to recoup the installation cost in $2\frac{1}{2}$ years. The main reasons for the use of static instead of rotary condensers in this particular instance were (*a*) low energy losses, (*b*) negligible maintenance costs, (*c*) ability to add extra units as necessity demands, (*d*) absence of special foundations. The specified energy losses of the rotary condenser at full load were 10 times greater than those of the static condenser, and subsequent experience with the latter showed that maintenance costs were practically nil. The following table gives the figures relating to each of the two alternatives, and shows a decided advantage in favour of the static condenser. This was amply confirmed by subsequent results.

Comparison of Static and Rotary Condensers.

		Static	Rotary
(*a*)	Capacity of condensers, kVA ..	1 500	1 500
(*b*)	Total cost (including switch-gear), £	7 200	4 500*
(*c*)	Cost per kVA, £	4·8	3·0
(*d*)	Energy losses at no load, kW ..	*nil*	55
(*e*)	Energy losses at full load, kW ..	7·5	75
(*f*)	Energy losses per annum, kWh..	47 500	475 000
(*g*)	Cost (at 0·75d. per kWh) of energy losses per annum, £ ..	148·5	1 485
(*h*)	kVA costs per annum (at £3 per kVA), £	22·5	225
(*k*)	Total: (*g*) + (*h*), £	171·0	1 710
(*l*)	Gross annual saving on kVA charges, £	3 078	3 078
(*m*)	Net annual saving on kVA charges: (*l*) − (*k*), £	2 907	1 368
(*n*)	Time required to pay off capital cost: (*b*) ÷ (*m*), years	2·5	3·3
(*o*)	Time "required" for delivery of plant, weeks	10	20
(*p*)	Delivery-date loss compared with static condenser, £	*nil*	263
(*r*)	Time required to pay off capital cost allowing for delivery-delay loss, years	2·5	3·5

The condenser is the most efficient piece of electrical apparatus there is, its efficiency lying between 99·3 and 99·98 per cent; the latter figure applies to the largest radio-frequency condensers. One of the most recent applications of condensers is the use of a group of condensers connected in series to a high-tension power line, with a resonant circuit connected to the lowest one in the series, whereby a small low-voltage load can be supplied economically from a high-voltage line. Again, the use of condensers for power-factor correction in connection with the modern high-frequency electric furnace, which operates at frequencies from 500 to 2 000 cycles per sec., has involved the development of special designs in which the losses are reduced to a minimum. Based on their cost per microfarad of capacitance, these condensers are more expensive than the types used on lower-frequency circuits, but the higher working frequency brings about such an increased loading that the cost per kVA of output is reduced.

* *World Power*, 1932, vol. 17, p. 386.

* Foundation cost not included.

Electric Boilers.

The use of the electric boiler is increasing in those countries where surplus energy is available, as is usually the case where hydro-electric stations are employed. By absorbing the excess energy the electric boiler is able to generate steam for manufacturing purposes and thus partially or wholly to replace existing fuel-fired boiler plants. It has been found that the size of an electric boiler may be predetermined by assuming that at a feed-water temperature of about 68° F. and at medium pressures, 1 kWh generates approximately $2\frac{3}{4}$ lb. of steam. This type of boiler would seem to have many advantages over fuel-fired boilers. Its space requirements are very small, and in most cases a separate boiler-house is not necessary. The floor space occupied by a recent 3-phase high-tension type developed by Penzold, having a rated capacity of 10 000 kW and a steam output of 28 000 lb. per hour, is only 280 sq. ft. Attendance is extremely simple, and the absence of fuel and ashes makes for clean operation. The boiler can be placed close to the steam consumer, thereby eliminating long pipe-lines and their attendant transmission losses. Owing to the fairly high average cost of current the use of the electric boiler in this country would appear to be limited to special isolated cases.

I have not time to describe the great strides made on the radio side of electrical engineering in direction- and position-finding and in reliable communication over long distances by means of short-wave transmission, or the successful development and manufacture by a British firm of a new type of steel-clad, demountable, continuously-evacuated transmitting valve, capable of dissipating 500 kW. Neither can I deal with the Drumm battery, or the apparently unlimited applications of the photo-electric cell. I have, however, said sufficient to indicate that in spite of the present economic stress the future of the electrical industry is full of promise so long as we aim at development on sane and sound lines.

Sheffield Students' Section.

I spent a good deal of time during last Session in attending as your representative the meetings of the Students' Section of this Sub-Centre, and I was greatly impressed by the high standard of papers intelligently read and discussed by its members. I should like to appeal to present heads of firms to give every encouragement to these young men of promise, these future engineers upon whom the conduct of our businesses, and, indeed, the future of England itself, depend. In this connection I would quote some sound advice given recently by Sir Duncan Watson to a young electrical engineer who had come to him for guidance. He said: " To get on, a young man needs brains, energy, and opportunity, and the greatest of these is opportunity. Avoid the shiftlessness that comes from the belief that success of any kind can come without hard work and disappointment."

INSTITUTION NOTES.

Members Visiting France.

The Council have entered into a reciprocal arrangement with the Société Française des Electriciens for the granting of privileges to visiting members on similar lines to those already in existence between the Institution and the American I.E.E. and other kindred institutions overseas.

Members of the Institution intending to visit France and wishing to avail themselves of this arrangement should apply to the Secretary for a letter of introduction to the Société Française des Electriciens and should state, for inclusion in the letter, the branch of the profession in which they are engaged, giving the name of the firm or company (if any) with which they are connected.

Overseas Members and the Institution.

During the three months ended the 31st December, 1932, the following members from overseas called at the Institution and signed the "Attendance Register of Overseas Members":—

Battiscombe, H. G. (Hong Kong).
Baxter, J. M. (Colombo).
Brasher, W. K., B.A. (Baghdad).
Collyer, J. K. (Cairo).
Davies, J. L. (Christchurch, N.Z.).
de Bruyn, W. (Arkonam, India).
Gibson, R. T. (La Paz, Bolivia).
Hawker, M. S. (Abadan, Persia).
Ilbert, O. L. (Shanghai).
Khanna, J. P. (Ajmer, India).
Lennane, W. Q. (Milan).
Meek, J., Jun., B.Sc.(Eng.), (Madras).
Morris, R. P. (Broken Hill, Rhodesia).
Murray, G. A. (Melbourne).
Patrick, W. McC. (Shanghai).
Poole, E. (Durban).
Scott, E. C., B.Sc. (Perak).
Stredwick, S. B. (Tanganyika).
Suggate, Major C. F. D., M.C. (Kirkee, India).
Surfleet, W. A. (Colombo).
Taylor, W. H. (Perth, W.A.).
Websdale, Major G. J., M.C. (Valparaiso).

National Certificates and Diplomas in Electrical Engineering (England and Wales).

The undermentioned colleges have been approved under the scheme drawn up by the Board of Education and the Institution.

Approved for Ordinary Grade Certificates (Senior Part-time Course).

Northwich, Verdin Technical College.
Tunbridge Wells Technical Institute.
Walthamstow Technical College.

Approved for Higher Grade Certificates (Advanced Part-time Course).

Norwich Technical College.
Treforest School of Mines.

World Power Conference.

The next Sectional Meeting will be held at Stockholm from the 26th June to the 10th July, 1933, and will deal with the energy problems of large-scale industry and transport. Arrangements have already been made for more than 170 papers and reports on these subjects. The Conference will include official visits and excursions in Sweden, Denmark, and Norway, with an optional extension to Finland.

British Standard Specifications.

The Institution of Electrical Engineers was closely associated with the formation, in 1901, of the Engineering Standards Committee, the forerunner of the British Standards Institution, and supports the work of that body both technically and financially. The I.E.E. Council recommend all the members to make the greatest possible use of the British Standard Specifications, the benefits to be derived from the adoption of which are not always fully realized. These specifications are drawn up with due regard to the community of interest of producer and purchaser, and are of great assistance in tendering, thus leading to the elimination of delay and to the introduction of economies in production and distribution. Consulting engineers and purchasers find that the use of these Specifications relieves their staffs of much routine work of a detailed nature, and also enables the required articles or materials to be obtained under fair trading conditions, and without the waste of time and material involved in the production of an unnecessarily large number of types and sizes of articles in common engineering use. The I.E.E. Wiring Regulations call for the use of apparatus in accordance with the appropriate British Standard Specifications. There are in all about 500 Specifications, over 100 of which relate directly to electrical engineering. A list of the Specifications (Ref. C.C. 7414) can be obtained on application to the Publications Department of the British Standards Institution, 28, Victoria-street, London, S.W.1. An Indexed List is also issued annually, price 1s.

Committees, 1932–33.

Among the Committees appointed* by the Council for 1932–33 are the following:—

INFORMAL MEETINGS COMMITTEE.

Mr. J. F. Shipley (*Chairman*).

Mr. G. F. Bedford.
Mr. A. G. Hilling.
Mr. A. N. D. Kerr.
Mr. H. M. Proud.
Mr. F. C. Raphael.
Dr. A. Rosen.
Mr. P. P. Wheelwright.
Mr. M. Whitgift.

And

A representative of the General Purposes Committee.
The Chairman of the Papers Committee.
The Chairman of the London Students' Section.

* The President is, *ex-officio*, a member of all Committees of the Institution.

Joint Committee for National Certificates and Diplomas in Electrical Engineering (England and Wales).

Prof. J. K. Catterson-Smith, M.Eng. .. .. } representing the I.E.E.
Mr. J. M. Kennedy ..
Prof. E. W. Marchant, D.Sc. .. ..

Dr. F. T. Chapman .. } representing the Board of Education.
Dr. A. Morley .. ..
Dr. C. F. Smith .. ..

Joint Committee for National Certificates and Diplomas in Electrical Engineering (Scotland).

Prof. G. W. O. Howe, D.Sc. } representing the I.E.E.
Mr. S. Mavor .. ..
Mr. Robert Robertson, B.Sc. .. .. ..
Prof. S. Parker Smith, D.Sc. .. .. ..

Dr. J. S. W. Boyle .. } representing the Scottish Education Department.
Mr. J. G. Frewin .. ..
Mr. W. Hyslop .. ..
Mr. F. W. Michie .. ..

Library and Museum Committee.

Col. R. E. Crompton, C.B.
The Rt. Hon. the Viscount Falmouth.
Mr. E. W. Hill.
Col. Sir Thomas F. Purves, O.B.E.
Dr. E. H. Rayner, M.A.

Local Centres Committee.

Mr. A. Ellis.
Mr. A. P. M. Fleming, C.B.E., M.Sc.
Lieut.-Col. H. E. O'Brien, D.S.O.
Col. Sir Thomas F. Purves, O.B.E.
Mr. L. Romero.
Mr. H. T. Young.

And the Chairman of each Local Centre and Sub-Centre.

Meter and Instrument Section Committee.

Mr. R. S. J. Spilsbury, B.Sc.(Eng.) (*Chairman*).

Mr. T. S. Andrew.
Mr. G. A. Cheetham.
Dr. C. V. Drysdale, C.B., O.B.E.
Mr. F. A. East, B.Sc.(Eng.).
Mr. E. W. Hill (Council representative).
Mr. Wilfred Holmes.
Mr. O. Howarth.
Mr. F. C. Knowles.
Mr. W. Lawson.
Prof. J. T. MacGregor-Morris.
Mr. F. E. J. Ockenden.
Dr. E. H. Rayner, M.A.
Mr. B. A. Robinson.
Mr. E. E. Sharp.

And the Chairman of the Papers Committee.

"Science Abstracts" Committee.

Mr. T. G. N. Haldane, M.A.
Mr. W. M. Mordey.
Mr. C. C. Paterson, O.B.E.
Mr. R. S. Whipple.

Dr. A. Ferguson, M.A. .. } representing the Physical Society of London.
Dr. D. Owen, B.A. ..
Dr. G. F. J. Temple ..
Prof. G. P. Thomson ..

Ship Electrical Equipment Committee.

Mr. A. G. S. Barnard.
Major B. Binyon, O.B.E., M.A.
Mr. J. H. Collie.
Mr. S. Harcombe, M.A., B.Sc.
Mr. A. Henderson.
Mr. J. F. W. Hooper.
Mr. P. V. Hunter, C.B.E.
Mr. J. W. Kempster.
Mr. A. C. Livesey.
Mr. S. W. Melsom.
Mr. N. W. Prangnell.
Col. A. P. Pyne.
Mr. P. Rosling.
Mr. T. A. Sedgwick.
Mr. F. H. Whysall.
Mr. H. D. Wight.
Mr. E. T. Williams, O.B.E.

And	*Representing*
Mr. A. E. Laslett, I.S.O.	Board of Trade.
Mr. W. McAuslan, Mr. James Barr .., Mr. T. R. Thomas	British Corporation for the Survey and Registry of Shipping.
Mr. H. C. Hazel ..	Electrical Contractors' Association.
Mr. J. Lowson ..	Electrical Contractors' Association of Scotland. Institution of Engineers and Shipbuilders in Scotland.
Mr. A. W. Stewart	Institution of Naval Architects.
Mr. J. Carnaghan	Lloyd's Register of Shipping.
Mr. A. B. Stewart	Lloyd's Underwriters' Association.
Mr. W. S. Wilson ..	N.E. Coast Institution of Engineers and Shipbuilders.

Wireless Section Committee.

Chairman: Mr. L. B. Turner, M.A.
Vice-Chairman: Dr. E. Mallett.

Mr. G. W. N. Cobbold, B.A.
Mr. H. Faulkner, B.Sc.
Mr. N. Lea, B.Sc.
Major S. H. Long, O.B.E., D.Sc.
Prof. J. T. MacGregor-Morris.
Mr. B. E. G. Mittell.
Mr. F. Murphy, B.Sc.(Eng.).
Mr. F. E. Nancarrow.
Mr. W. J. Picken.
Mr. E. H. Shaughnessy, O.B.E.
Mr. G. Shearing, B.Sc.
Mr. T. Wadsworth.

A representative of the Council.
The Chairman of the Papers Committee.

And the following representatives of Government Departments:—
Admiralty: Capt. A. J. L. Murray, D.S.O., O.B.E., R.N.
Post Office: Col. A. S. Angwin, D.S.O., M.C., B.Sc. (Eng.).
Air Ministry: Mr. F. S. Barton, M.A., B.Sc.
War Office: Major J. R. Carter, O.B.E.

Wiring Regulations Committee.

Mr. Ll. B. Atkinson.
Mr. H. J. Cash.
Mr. J. R. Cowie.
Mr. P. Good.
Mr. R. Grierson.
Mr. J. F. W. Hooper.
Mr. H. Marryat.
Mr. S. W. Melsom.
Mr. F. W. Purse.
Col. A. P. Pyne.
Mr. H. W. H. Richards.
Mr. E. Ridley.
Mr. L. Romero.
Mr. P. Rosling.
Mr. J. W. J. Townley.

And	*Representing*
Mr. H. W. Couzens	Association of Consulting Engineers.
Mr. W. Lang ..	Association of Supervising Electrical Engineers.
Mr. E. B. Wedmore	British Electrical and Allied Industries Research Association.
Mr. H. H. Berry .. Mr. F. Broadbent Mr. J. R. Dick, B.Sc. Mr. A. R. Everest Mr. J. B. Tucker .. Mr. A. J. L. Whittenham	British Electrical and Allied Manufacturers' Association.
Mr. W. F. Bishop	Cable Makers' Association.
Mr. W. R. Rawlings Mr. E. A. Reynolds	Electrical Contractors' Association.
Mr. R. A. Ure ..	Electrical Contractors' Association of Scotland.
Mr. J. Howard-Blood Mr. E. B. Hunter Mr. W. B. Trafford	Fire Offices Committee.
Mr. R. W. L. Phillips Mr. W. C. P. Tapper	Incorporated Municipal Electrical Association.
Mr. E. W. Farr ..	Independent Cable Makers' Association.

Representatives of the Institution on Other Bodies.

The following is a list of representatives of the Institution on other bodies, and gives the dates on which they were appointed:—

Bristol University:

Mr. H. F. Proctor (8 Jan., 1925).

British Cast Iron Research Association:

Mr. E. B. Wedmore (25 Sept., 1924).

British Electrical and Allied Industries Research Association:

Council:

Mr. J. M. Donaldson, M.C. (18 Dec., 1930).
Mr. C. P. Sparks, C.B.E. (18 Dec., 1930).

Sub-Committee on Connections to Large Gas-filled Lamps:

Mr. C. C. Paterson, O.B.E. (24 Oct., 1929).
Mr. B. Welbourn (24 Oct., 1929).

Sub-Committee on Earthing and Earth Plates:

Mr. S. W. Melsom (31 Jan., 1930).

British Electrical Development Association:

Council:

Mr. R. Grierson (21 Jan., 1932).
Mr. E. E. Sharp (21 Jan., 1932).
Mr. H. T. Young (16 Feb., 1928).

Electric Vehicle Committee:

Col. R. E. Crompton, C.B. (22 Oct., 1925).

Committee on Rural and Agricultural Electrification:

Mr. J. M. Donaldson, M.C. (20 Oct., 1927).
Mr. R. Grierson (20 Oct., 1927).

British Standards Institution:

Engineering Divisional Council:

Mr. Ll. B. Atkinson (31 Mar., 1930).
Col. R. E. Crompton, C.B. (31 Mar., 1930).
Mr. C. P. Sparks, C.B.E. (31 Mar., 1930).

Electrical Industry Committee:

Dr. W. H. Eccles, F.R.S. (17 Feb., 1927).
Lt.-Col. K. Edgcumbe, T.D., R.E.T.(Ret.) (5 Mar., 1925).
Mr. F. Gill, O.B.E. (21 May, 1914).
Mr. J. S. Highfield (21 May, 1914).
Mr. R. T. Smith (21 May, 1914).

Technical Committee on Electric Clocks:

Mr. W. Lang (28 April, 1932).

Technical Committee on Electric Power Cables:

Mr. S. W. Melsom (10 Jan., 1930).

Technical Committee on Electric Signs:

Mr. L. Barlow (14 May, 1931).
Mr. R. W. L. Phillips (17 Feb., 1932).

Technical Committee on Electrical Accessories:

Mr. H. J. Cash (31 Mar., 1925).
Mr. F. W. Purse (31 Mar., 1925).

Technical Committee on Electrical Instruments:

Lt.-Col. K. Edgcumbe, T.D., R.E.T. (Ret.) (15 Feb., 1923).

Technical Committee on Electrical Nomenclature and Symbols:

Mr. C. C. Paterson, O.B.E. (8 Jan., 1920).

Technical Committee on Electricity Meters:

Mr. A. J. Gibbons (28 Mar., 1930).
Mr. S. W. Melsom (21 Jan., 1926).
Mr. G. F. Shotter (28 Feb., 1929).

Technical Committee on Letter Symbols:

Mr. A. T. Dover (21 Nov., 1929).

Technical Committee on Overhead Transmission Lines Material:

Mr. P. Rosling (5 Mar., 1925).

Technical Committee on Standardization of Wireless Apparatus and Components:

Mr. E. H. Shaughnessy, O.B.E. (30 Sept., 1925).

Sub-Committee on Ceiling Roses:

Mr. H. J. Cash (23 Jan., 1924).
Mr. F. W. Purse (23 Jan., 1924).

Sub-Committee on Conduit Fittings:

Mr. H. J. Cash (18 May, 1927).

Sub-Committee on Connectors for Portable Domestic Apparatus:

Mr. H. J. Cash (23 Jan., 1924).
Mr. H. W. Couzens (26 Oct., 1932).
Mr. F. W. Purse (23 Jan., 1924).

Sub-Committee on Connectors for Radio Apparatus:

Mr. R. W. L. Phillips (6 Jan., 1931).

Sub-Committee on Distribution Boards:
Mr. E. B. Hunter (25 Feb., 1927).
Mr. S. W. Melsom (25 Feb., 1927).

Sub-Committee on Low-Voltage Cut-outs.
Mr. H. J. Cash (22 June, 1926).
Mr. E. B. Hunter (25 Feb., 1927).
Mr. S. W. Melsom (25 Feb., 1927).

Sub-Committee on Mains Supply Apparatus:
Mr. R. W. L. Phillips (11 Dec., 1930).
Mr. F. W. Purse (16 Oct., 1928).

Sub-Committee on Radio Nomenclature and Symbols:
Col. A. S. Angwin, D.S.O., M.C., B.Sc.(Eng.) (7 April, 1932).

Sub-Committee on Wall-plugs and Sockets:
Mr. H. J. Cash (23 Jan., 1924).
Mr. H. W. Couzens (26 Oct., 1932).
Mr. F. W. Purse (23 Jan., 1924).

Sub-Committee on Protected-type Plugs and Sockets:
Mr. H. J. Cash (26 Oct., 1932).
Mr. H. W. Couzens (26 Oct., 1932).
Mr. F. W. Purse (26 Oct., 1932).

Sub-Panel on Graphical Symbols for Interior Installations:
Mr. J. R. Cowie (13 Nov., 1924).

Illumination Industry Committee:
Lt.-Col. K. Edgcumbe, T.D., R.E.T. (Ret.) (28 Feb., 1924).
Mr. P. Good (28 Feb., 1924).
Mr. H. T. Harrison (28 Feb., 1924).
Prof. J. T. MacGregor-Morris (28 Feb., 1924).
Mr. J. M. G. Trezise (19 Mar., 1925).

Technical Committee on Engine Testing Fittings:
Mr. W. M. Selvey (4 Aug., 1931).

Technical Committee on Coal:
Mr. W. M. Selvey (19 Jan., 1928).

Technical Committee on Colliery Requisites:
Mr. C. T. Allan (3 July, 1924).

Birmingham Regional Committee:
Mr. F. C. Hall.

Glasgow Regional Committee:
Mr. F. Anslow.

Manchester Regional Committee.
Mr. W. T. Anderson.

Newcastle Regional Committee:
Mr. S. A. Simon.

Sheffield Regional Committee:
Mr. M. Wadeson.

Technical Committee on Fans:
Mr. R. O. Kapp (22 Oct., 1931).

Technical Committee on Land Boilers:
Mr. W. E. Highfield (2 July, 1931).
Mr. W. M. Selvey (7 April, 1932).

Sub-Committee on Accessories:
Mr. W. M. Selvey (7 April, 1932).

Sub-Committee on Boiler and Superheater Tubes:
Mr. W. M. Selvey (7 April, 1932).

Sub-Committee on Fittings:
Mr. W. M. Selvey (7 April, 1932).

Sub-Committee on Water-Tube Boilers:
Mr. W. M. Selvey (7 April, 1932).

Technical Committee on Larch Poles:
Mr. B. Welbourn (21 Jan., 1932).

Technical Committee on Tramway Poles.
Mr. T. L. Horn (4 Feb., 1926).

Technical Committee on Pipe Flanges:
Mr. W. M. Selvey (14 April, 1921).

Technical Committee on Pump Tests:
Mr. R. S. Allen (2 July, 1931).

Technical Committee on Railway Signalling Apparatus:
Mr. A. F. Bound (24 Oct., 1929).

Technical Committee on Rating of Rivers:
Mr. G. K. Paton (20 Oct., 1927).

Technical Committee on Rubber Belting:
Mr. C. Rodgers, O.B.E., B.Sc., B.Eng. (5 Jan., 1928).

Sub-Committee on Mining Electrical Plant:
Captain A. C. Sparks (27 Mar., 1930).

Sub-Committee on Portable Railway Track:
Mr. R. T. Smith (25 Oct., 1928).

Petroleum Industry Committee:
Mr. H. W. Clothier (1 Feb., 1923).

Building Industry, National Council for:
Mr. F. W. Purse (20 Oct., 1932).
Mr. H. T. Young (20 Oct., 1932).

City and Guilds of London Institute, Fellowship Committee:
Dr. W. H. Eccles, F.R.S. (19 April, 1928).

City and Guilds of London Institute—Telegraphy, Telephony, and Radio Communication Advisory Committee:
Mr. E. H. Shaughnessy (22 Oct., 1931).

Council for the Preservation of Rural England:
Mr. J. M. Kennedy (10 Jan., 1929).

Electrical Association for Women:
Council:
Mr. A. P. M. Fleming, C.B.E., M.Sc. (18 Dec., 1924).

Committee for Training of Women Demonstrators:
Mr. E. E. Sharp (5 Nov., 1931).

Engineering Joint Council:
Col. Sir Thomas F. Purves, O.B.E. (24 Oct., 1929).
Mr. J. M. Donaldson (11 Feb., 1932).

Imperial College of Science and Technology, Governing Body:
Mr. W. M. Mordey (12 April, 1923).

Imperial Minerals Resources Bureau Conference, Copper Committee:
Mr. B. Welbourn (18 Sept., 1919).

Institute of Metals, Corrosion Research Committee:
Mr. W. M. Selvey (19 July, 1923).

Institution of Civil Engineers, Engine and Boiler Testing Committee:
Mr. R. A. Chattock (19 Oct., 1922).
Mr. C. P. Sparks, C.B.E. (19 Oct., 1922).

International Association for Testing Materials:
Mr. J. M. Kennedy (5 July, 1928).

International Illumination Commission, British National Illumination Committee:
Lt.-Col. K. Edgcumbe, T.D., R.E.T. (Ret.) (27 Nov., 1913).
Mr. P. Good (18 Sept., 1919).
Mr. H. T. Harrison (27 Nov., 1913).
Prof. J. T. MacGregor-Morris (27 Nov., 1913).
Mr. J. M. G. Trezise (19 Mar., 1925).

Joint Fuel Committee:
Mr. R. A. Chattock (7 Jan., 1932).
Mr. C. P. Sparks, C.B.E. (7 Jan., 1932).

Leeds Municipal Technical Library Committee:
Mr. W. B. Woodhouse (19 Dec., 1918).

Loughborough Technical College, Advisory Committee:
Mr. Ll. B. Atkinson (11 April, 1929).

Metalliferous Mining (Cornwall) School, Governing Body:
Mr. L. A. Hards (1 Dec., 1927).

Middlesbrough Technical College, Governing Body:
Mr. E. Edwards (1 Oct., 1925).
Mr. J. M. Gibson (1 Oct., 1925).

National Certificates and Diplomas in Electrical Engineering, Joint Committee (England and Wales):
Prof. J. K. Catterson-Smith, M.Eng. (3 Feb., 1932).
Mr. J. M. Kennedy (5 Nov., 1931).
Prof. E. W. Marchant, D.Sc. (5 Jan., 1928).

National Certificates and Diplomas in Electrical Engineering, Joint Committee (Scotland):
Prof. G. W. O. Howe, D.Sc. (6 Nov., 1930).
Mr. S. Mavor (6 Nov., 1930).
Mr. R. Robertson, B.Sc. (6 Nov., 1930).
Prof. S. Parker Smith, D.Sc. (6 Nov., 1930).

National Physical Laboratory, General Board:
Mr. C. C. Paterson, O.B.E. (3 Nov., 1932).
Col. Sir Thomas F. Purves (21 Nov., 1929).

National Register of Electrical Contractors:
Mr. H. J. Cash (12 March, 1931).
Mr. P. V. Hunter, C.B.E. (18 Feb., 1926).
Mr. W. R. Rawlings (18 Feb., 1926).
Mr. W. M. Selvey (18 Feb., 1927).

National Smoke Abatement Society:
Lt.-Col. W. A. Vignoles, D.S.O. (12 June, 1930).
Mr. W. C. P. Tapper (12 June, 1930).

Professional Classes Aid Council:
Mr. P. F. Rowell (20 April, 1928).

Radio Manufacturers' Association, Committee on Battery Eliminators:
Mr. J. R. Dick, B.Sc. (3 April, 1928).

Royal Engineer Board:
Mr. W. B. Woodhouse (19 Mar., 1925).

Royal Society:
National Committee on Physics:
Mr. C. C. Paterson, O.B.E. (6 Nov., 1930).

National Committee on Radio-Telegraphy:
Prof. C. L. Fortescue, O.B.E., M.A. (20 Oct., 1927).
Mr. E. H. Shaughnessy, O.B.E. (6 Nov., 1930).

Science Museum, South Kensington, Advisory Council:
Mr. W. M. Mordey (10 April, 1930).

Town Planning Institute, Committee on Overhead Transmission Lines:
Mr. J. M. Kennedy (7 April, 1932).

Union of Lancashire and Cheshire Institutes (Panel for Engineering):
Mr. A. P. M. Fleming, C.B.E., M.Sc. (28 Feb., 1924).
Prof. Miles Walker, D.Sc. (28 Feb., 1924).

War Office Mechanical Warfare Board:
Dr. W. H. Eccles, F.R.S. (19 Jan., 1928).

Women's Engineering Society:
Mr. A. P. M. Fleming, C.B.E., M.Sc. (25 Sept., 1924).

World Power Conference (British National Committee):
Mr. Roger T. Smith (1 May, 1930).

Elections and Transfers of Members.

At the Ordinary Meeting held on the 3rd November, 1932, the following elections and transfers were effected:—

ELECTIONS.

Associate Members.

Banerji, Shyamananda, B.A., B.Sc.Tech.
Barnett, Rowland Hill.
Bennett, William Alfred.
Binns, Edward.
Chapman, Frank Morrice, B.E.
Dale, Geoffrey Henry.
Dale, Leslie Cyril Ll., M.Sc.(Eng.).
Giacomuzzi, Luciano, Dott.Ing.
Gillies, James Ford, B.E., B.Sc.(Eng.).
Grubb, Henry.
Gurnhill, John Byron.
Hardy, Vernon Clavering, B.A.
Itin, Issay.
Martin, John Arthur S.
Martin, Ralph Otway.
Nattrass, Henry, B.Sc.
Orkney, John Carnegie, B.Sc.
Osborne, Robert Morris, B.E.E.
Pollard, George Leslie G., Major, R.S.
Salter, Jack, B.Sc.Tech.
Sieveking, Herbert Alfred, M.Sc.(Eng.).
Spiby, James.
Whittle, Norman Edward.

Companion.

Fraser, Kenneth.

Associates.

Adam, James Easton.
Drake, Herbert Harry.
King, Ernest Henry.
Mant, Charles William.
Prowse, Harold Short.
Reilly, Stephen.

Graduates.

Baxter, Philip.
Birdy, Framroze Rustomji.
Bowerbank, Geoffrey, B.Sc.
Chapman, Ernest Edward, B.Sc.(Eng.).
Chen, Seaton Hsun.
Clark, Francis James, B.Sc.
Edwards, Henry John.
Findlay, Alexander Byars.
Fleming, Jack Morris, B.A., B.Sc.Tech.
Garth, Herbert Leslie.
Hodgetts, Eric.
Isaac, Thomas Cullingford.
Kumar, Pyare Lal.
Massey, Keppel Fletcher, M.A.
Mehta, Jehangir Shapurji.
Metcalf, Alfred Guest, B.Sc.(Eng.).
Mukerji, Pramatha Nath, M.Sc.
Nicholson, John Duncan, B.Sc.
Oxbrow, Cyril Frank, B.Sc.
Patel, Boman Jamsetji.
Read, James William, B.Sc.
Robertson, William Kemp, B.E.
Tattershall, James.
Thadani, Alimhand Bulchand, M.Sc.(Eng.).
Urch, Reginald John.
Webber, Frederick William J.
Wells, Lancelot Ernest W.
Woodward, Clement Ralph.

Students.

Aggarwal, Parshotam Lal.
Armstrong, Robert George.
Banks, Bertram Owen.
Bazin, James Michael.
Beale, Eustace Herbert K.
Benson, Cyril.
Bishop, Arthur Rowsell.
Brigstocke, William George P.
Brown, James Kennedy J.
Bullough, Frank Peter.
Bundell, Cyril Hughes.
Chopra, Hazari Lall.
Cooke, George Frazer.
Coope, Leslie.
Corney, Lawrence Arthur.
de Souza, Alick Desiderio.
Ecclestone, Herbert James.
Ellis, Alexander.
Emeny, Harold Charles.
Evans, John Awstin.
Evans, Lloyd Phillips.
Foster, Michael George.
Gilkes, John William.
Graham, James Wilfred.
Griffith, George William S.
Hales, Thomas John.
Hancock, Reginald H.
Hassan, Mirza Marghole.
Hill, Arthur.
Holmes, Douglas.
Hunt, Eric.
Jenkin, Norman.
Kari, Mohamad Sadiq.
Knott, William Roderick.
Louie, Harold William H.
McGibbon, Robert Stewart.
Maddick, Horace Leonard.
Marathe, Sitaram Shridhar.
Marshall, Cyril George.
Morris, Alec.
Nath, K. Viswanathan.
Nicoll, John Graham D., B.A.
North, Leonard.
Parris, Edward Arthur S.
Pulling, Ralph Henry.
Rahmani, Baggu Khan.
Ramachandra, G. Saligram.
Rattue, Percy John.
Rider, Stewart Douglas O.
Roberts, Frederick Charles.
Rule, Frank Thomas.
Russell, Vernon Arthur.
Shepherd, Leslie.
Smith, Frank John.
Stephenson, Ernest.
Stobie, Peter Douglas H.
Tarbatt, George Edric.
Vohra, Darshan Singh.
Watson, John Garth.
Weerasena, Dias de Silva.
Wells, Herbert Joseph S.
Windsor, Edward.
Woodward, Joseph Denis.
Wright, John Stanley.

TRANSFERS.

Associate Member to Member.

Baldwin, Sydney James W.
Goodman, Cyril William, B.E.
Narayan, Professor Shiv, M.A., B.Sc., B.E.
Perks, John Noel R., M.A.
Ryder, Percy George.
Unwin, Frederic Ralph.

Associate to Associate Member.

Attkins, Roy James.
Bradford, Wilfred Brittain.
Cooper, Walter Dunbar.
Goodman, Reginald Alfred.
Jones, Joseph.
Williams, Daniel John.

Graduate to Associate Member.

Beaglehole, Keith, B.Sc.
Beale, Herbert Rene.
Bell, Robert.
Berry, James Begg.
Bissell, Frank Edwin G.
Buckley, Sidney Ernest, B.Sc.
Catling, Alan Benjamin.
Clark, Ernest Cameron, B.Sc.
Cole, Frank Jasper.
Crews, Thomas John.
Crook, Edward Howard
Davey, Cyril Frederick, B.Sc.(Eng.).
Davies, Wilfred Thomas.
Deakin, George Woolliscroft, B.Sc.(Eng.).
Duckworth, Arthur William S.
Filbey, Charles Albert.
Fitzpayne, Eric Richard L., B.Sc.
Gardiner, Robert, B.Sc.Tech.
Harper, Harold James, B.Sc.(Eng.).
Harvey, Leonard.
Holt, Walter Raymond K.
Horrell, John Culwick.
Jordan, Reginald John.
Lord, Will.
Marchant, Eric Walford, B.Eng.
Mundie, Colin Macpherson.
Pearson, George Lincoln, B.Sc.(Eng.).
Price, Joshua Marshall.
Selvey, Arthur Morrish.
Smillie, John, B.Sc.
Somerville, Arthur Walter M.
Telfer, John, B.Sc.
Wolfe, Standish Smyth.
Woodhouse, Lionel Clayton, M.A.

Student to Associate Member.

Meers, Richard Adney.
Pearson, George Matthew, B.Sc.Tech.

Student to Associate.

Breckell, Henry.

In addition, the following transfers have been effected by the Council:—

Student to Graduate.

Beavis, Cuthbert John.
Billington, Reginald Moreton.
Care, Norman.
Cheetham, William Ernest.
Dobelli, Alfred Clive, B.Sc.(Eng.).
Handley, Eric Thomas.
Harley, John.
Higginbottom, Frank.
Inglis, Felix Stevens.
Irons, John McAdoo.
Jackson, George.
Jefferson, Sidney, B.Sc.(Eng.).
Lester, Reginald Charles W.
Makaroff, Igor, B.Sc.(Eng.).
Marshall, Joseph Ernest, B.Eng.
Master, Rustam Jehangir.
May, Gilbert.
Mendelson, John.
Morris, Thomas Bilson.
Newling, Sidney Kenneth.
Newman, Frank Samuel.

Student to Graduate—continued.

Patel, Motilal Lallubhai.
Pletts, John William, B.Sc.(Eng.).
Ray, Binoy Bhusan, B.Sc.(Eng.).
Richmond, Herbert Stewart.
Rousell, Sydney Michael E.
Stonelake, William Henry, B.Sc.(Eng.).
Sumpner, Robert Martin, B.Sc.(Eng.).
Symes, George Leslie.
Wearmouth, Albert.
Westmorland, Roy William.
Wilson, Gavin Trencove, B.E.
Wood, Arthur John.
Yeo, Philip Henry.
Youatt, David.

Accessions to the Lending Library.

ACADEMY OF MOTION PICTURE ARTS AND SCIENCES. Recording sound for motion pictures. Edited by L. Cowan. 8vo. 419 pp. *New York*, 1931

ADMIRALTY, THE. Admiralty handbook of wireless telegraphy, 1931. 8vo. 1020 pp. *London*, 1932

ALLEN, H. S., *F.R.S.* Electrons and waves; an introduction to atomic physics. sm. 8vo. 345 pp. *London*, 1932

APPLETON, E. V., *M.A.*, *D.Sc.*, *F.R.S.* Thermionic vacuum tubes and their applications. sm. 8vo. 124 pp. *London*, [1932]

ATTWOOD, S. S. Electric and magnetic fields. 8vo. 325 pp. *New York*, 1932

BELL, A. H. The exponential and hyperbolic functions and their applications. sm. 8vo. 93 pp. *London*, 1932

BENNETT COLLEGE. Automatic telephony. Edited by W. S. Procter. la. 8vo. 464 pp. *Sheffield, n.d.*

—— Electrical design. Edited by H. G. McClean. la. 8vo. 471 pp. *Sheffield, n.d.*

—— Electrical distribution. Edited by G. D. Dewar. la. 8vo. 293 pp. *Sheffield, n.d.*

—— Electricity. Revised by C. Sylvester. 5 vol. la. 8vo. *Sheffield, n.d.*

BIRD, G. W. Examples in engineering design, being a revised and enlarged edition of "Examples in machine design." Containing many typical designs illustrating standard engineering practice suitable for students taking this subject for an engineering degree examination. obl. 4to. 109 pp. *London*, 1930

BISHOP, R. A. The electric trolley bus for transport managers, electrical engineers and others who wish to know the possibilities of this system of traction, and who require authoritative details of operating charges and costs of conversion of an existing tramway system. 8vo. 204 pp. *London*, 1931

BOLTZ, C. L. Everyman's wireless. 8vo. 335 pp. *London*, [1932]

BOWERS, E. L., *Ph.D.*, and ROWNTREE, R. H. Economics for engineers. 8vo. 498 pp. *New York*, 1931

BRAYMER, D. H., and ROE, A. C. Rewinding and connecting alternating-current motors. 8vo. 387 pp. *New York*, 1932

BROWN, B. Talking pictures: a practical and popular account of the principles of construction and operation of the apparatus used in making and showing sound films. 8vo. 316 pp. *London*, 1931

BROWN, H. A. Radio frequency electrical measurements. 8vo. 397 pp. *New York*, 1931

CANFIELD, D. T. Vector representation for electrical metermen. 8vo. 191 pp. *New York*, 1931

CODD, A. M. Electric wiring diagrams for motor vehicles; embracing all the leading systems of lighting, starting and ignition for British, American and European motor vehicles. 4th ed. 8vo. 267 pp. *London*, 1932

COPPOCK, C. Electric train-lighting: theory and practice. 8vo. 159 pp. *London*, 1931

CRAMP, W., *D.Sc.* Michael Faraday and some of his contemporaries. sm. 8vo. 77 pp. *London*, 1931

CRAWLEY, *Lt.-Col.* C. From telegraphy to television: the story of electrical communications. 8vo. 224 pp. *London*, [1931]

DARWIN, C. G., *M.A.*, *F.R.S.* The new conceptions of matter. 8vo. 200 pp. *London*, 1932

DE GIULI, I. Submarine telegraphy: a practical manual. Transl. from the Italian by J. J. MacKichan. With a foreword by T. E. Herbert. 8vo. 235 pp. *London*, 1932

DINSDALE, A. First principles of television. 8vo. 256 pp. *London*, 1932

DUNCAN, R. L., and DREW, C. E. Radio telegraphy and telephony: a complete textbook for students of wireless communication. 2nd ed. 8vo. 1057 pp. *New York*, 1931

EVERITT, W. L. Communication engineering. 8vo. 575 pp. *New York*, 1932

FELIX, E. H. Television: its methods and uses. 8vo. 282 pp. *New York*, 1931

FERNS, J. L. Meter engineering; a practical book on the installation, testing, and maintenance of electricity meters. sm. 8vo. 278 pp. *London*, 1932

FISHER, H. K. C., and DARBY, J. C. H. Students' guide to submarine cable testing. 3rd ed. 8vo. 244 pp. *London, n.d.*

FORSYTH, A. R., *Sc.D.*, *LL.D.*, *F.R.S.* A treatise on differential equations. 6th ed. 8vo. 601 pp. *London*, 1929

—— Solutions of the examples. 2nd ed. 8vo. 256 pp. *London*, 1923

GANS, R. Vector analysis, with applications to physics. Authorized translation from the 6th German edition by W. M. Deans. 8vo. 172 pp. *London*, 1932

GILBERT, T. C. Artificial earthing for electrical installations. (Automatic safety switching.) Preface by F. W. Purse. 8vo. 173 pp. *London*, [1932]

HADDON, R. A compendium of patents and designs law and practice, comprising . . . practice and forms in Great Britain, and all foreign countries and colonies. 8vo. 615 pp. *London*, 1931

HAGUE, B., *D.Sc.* Alternating current bridge methods; for the measurement of inductance, capacitance, and effective resistance at low and telephonic frequencies. 3rd ed. 8vo. 438 pp. *London*, 1932

HARRIS, D. T., *M.B.*, *D.Sc.* The technique of ultraviolet radiology. sm. 8vo. 174 pp. *London*, 1932

HECKSTALL-SMITH, H. W. Intermediate electrical theory. sm. 8vo. 530 pp. *London*, [1932]

HENLEY'S TELEGRAPH WORKS CO., LTD. Practical cable jointing. sm. 8vo. 215 pp. *London*, [1932]

HERBERT, T. E., and PROCTER, W. S. Telephony; a detailed exposition of the telephone system of the British Post Office. 2nd ed. vol. 1, Manual switching systems and line plant.
8vo. 1239 pp. *London*, 1932

HIRST, A. W. Direct current machine design.
8vo. 187 pp. *London*, 1931

HOPKINS, R. E. Induction motor practice: a special treatment of the subject for students, young designers and sales engineers.
8vo. 374 pp. *London*, 1932

HUGHES, A. LL., *D.Sc.*, and DU BRIDGE, L. A., *Ph.D.* Photoelectric phenomena.
8vo. 543 pp. *New York*, 1932

JENKIN, F., *F.R.S.* Electricity and magnetism.
sm. 8vo. 414 pp. *London*, 1914

JONES, B. E. The practical super-het. book. With an introduction by J. A. J. Cooper. Edited by B. E. J.
sm. 8vo. 140 pp. *London, n.d.*

—— The practical wireless data book, containing in simple form the essential facts, figures and formulæ relating to the design and construction of wireless receiving apparatus. Edited by B. E. J.
sm. 8vo. 140 pp. *London*, [1926]

JONES, E. T., *D.Sc.* Induction coil; theory and application. 8vo. 252 pp. *London*, 1932

JOHNSON AND PHILLIPS, LTD. The J. and P. marine cable book. 8vo. 107 pp. *London*, 1931

KESSELRING, F., *Dr.-Ing.* The elements of switchgear design. Transl. by S. R. Mellonie and J. Solomon.
sm. 8vo. 189 pp. *London*, 1932

KEMP, P., *M.Sc.* Electrical machinery and apparatus manufacture. A complete work by practical specialists. . . . Edited by P. K.
7 vol. sm. 8vo. *London*, 1931–32

vol. 1. Direct current machines, by H. V. Shove.
Cable construction, by M. C. Timms.
Transformer manufacture, by P. Kemp.
vol. 2. Electric lamps, by F. J. Hawkins.
Design and the drawing office, by P. P. Starling.
Insulators and insulating material, by A. Collins.
Electrical materials, by M. G. Say.
vol. 3. Small electric motors, by C. B. Crofts and F. Harrabin.
Works organization and administration, by A. P. M. Fleming.
Measuring instruments, by C. L. Lipman.
Domestic apparatus, by W. J. Simms.
Telephone apparatus, by G. A. M. Hyde.
vol. 4. Thermionic valves, by L. S. Harley.
Low-tension switchgear, by W. F. N. Harper.
Armatures and field magnets, by F. W. Davies.
Primary cells, by H. J. Stern.
vol. 5. Electric furnace construction, by A. G. Robiette.
Testing, by H. Cotton.
Accumulators, by E. S. Chapman.
vol. 6. Turbo-alternators, by W. D. Horsley.
Telegraph instruments, by O. E. Brenner.
vol. 7. High-tension switchgear, by W. A. A. Burgess.
A.C. motors and generators, by R. Marsden.

LANGSDORF, A. S. Principles of direct-current machines. 4th ed. 8vo. 612 pp. *New York*, 1931

LADNER, A. W., and STONER, C. R. Short-wave wireless communication. 8vo. 358 pp. *London*, 1932

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8vo. 384 pp. *London*, 1932

LIVENS, G. H., *M.A.* The theory of electricity. 2nd ed.
8vo. 427 pp. *Cambridge*, 1926

LODGE, *Sir* O., *D.Sc.*, *F.R.S.* Past years: an autobiography. 8vo. 364 pp. *London*, 1931

LOW, B. B. Mathematics: a text-book for technical students. 8vo. 455 pp. *London*, 1931

LUCKIESH, M., *D.Sc.*, and MOSS, F. K. Seeing: a partnership of lighting and vision.
8vo. 274 pp. *Baltimore*, 1931

MCLEAN, G. O. Steam power stations; equipment and maintenance. sm. 8vo. 113 pp. *London*, 1932

MAYCOCK, W. P. Alternating-current work. 2nd ed.
sm. 8vo. 452 pp. *London*, 1929

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MOULLIN, E. B. The principles of electromagnetism.
8vo. 287 pp. *Oxford*, 1932

NATIONAL ELECTRIC LIGHT ASSOCIATION. Relay handbook supplement
sm. 8vo. 420 pp. *New York*, 1931

PALLOT, A. C. The engineering equipment of buildings. With a foreword by H. Baines.
8vo. 355 pp. *London*, 1932

PALMER, W. T. Outline notes on telephone transmission theory. With a foreword by W. Cruickshank.
8vo. 168 pp. *London*, [1932]

PICKWORTH, C. N. The slide rule: a practical manual. 14th ed. sm. 8vo. 124 pp. *Manchester*, [1916]

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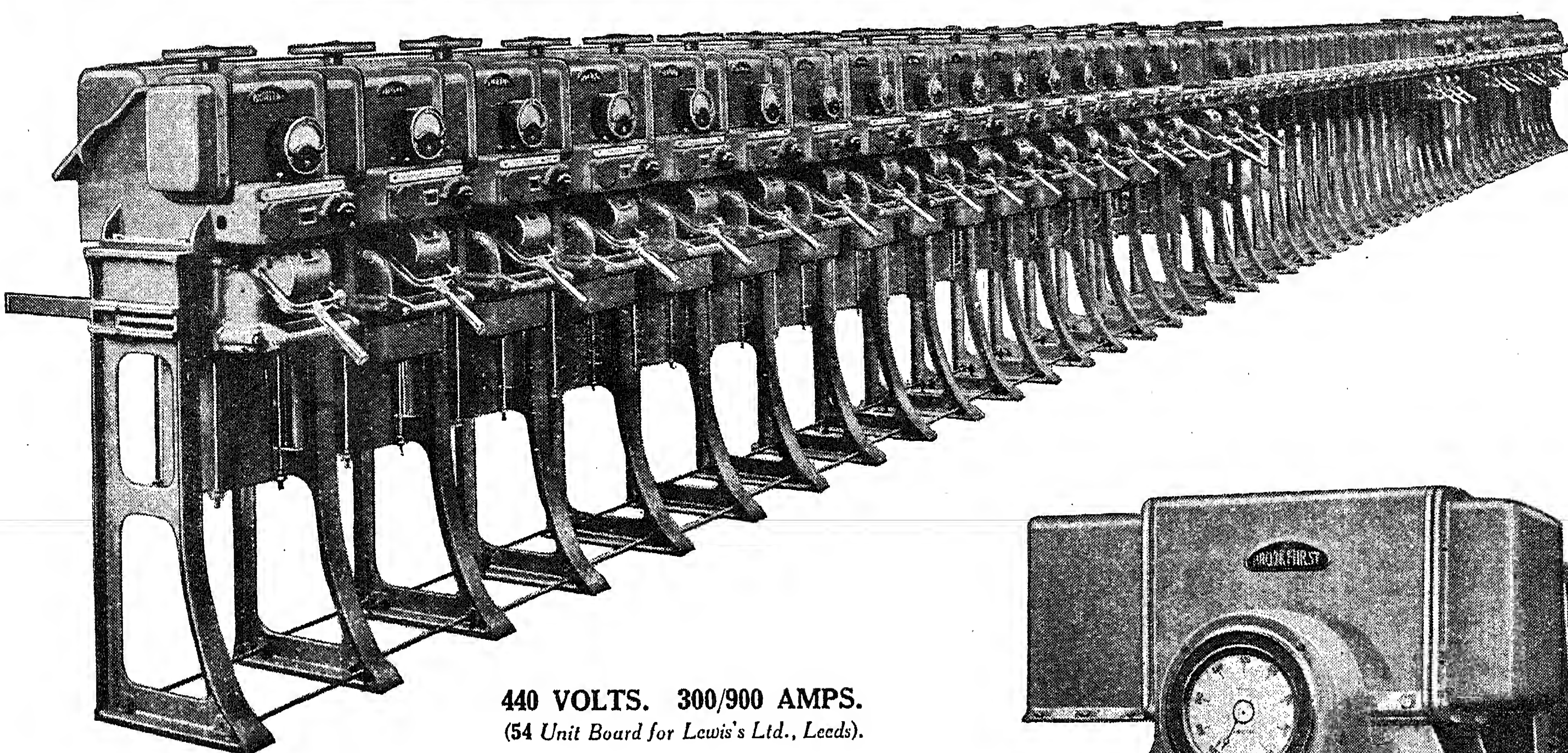

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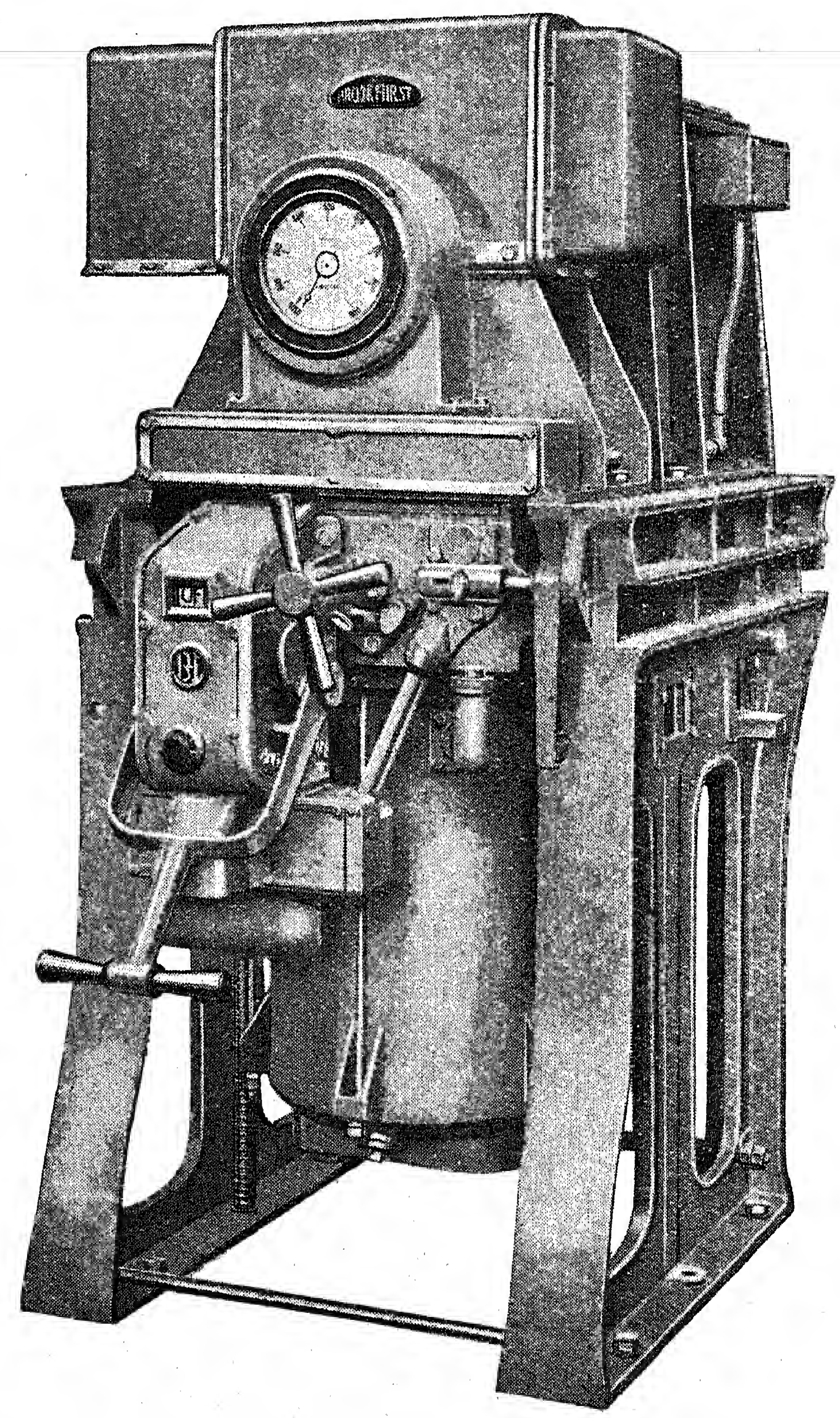

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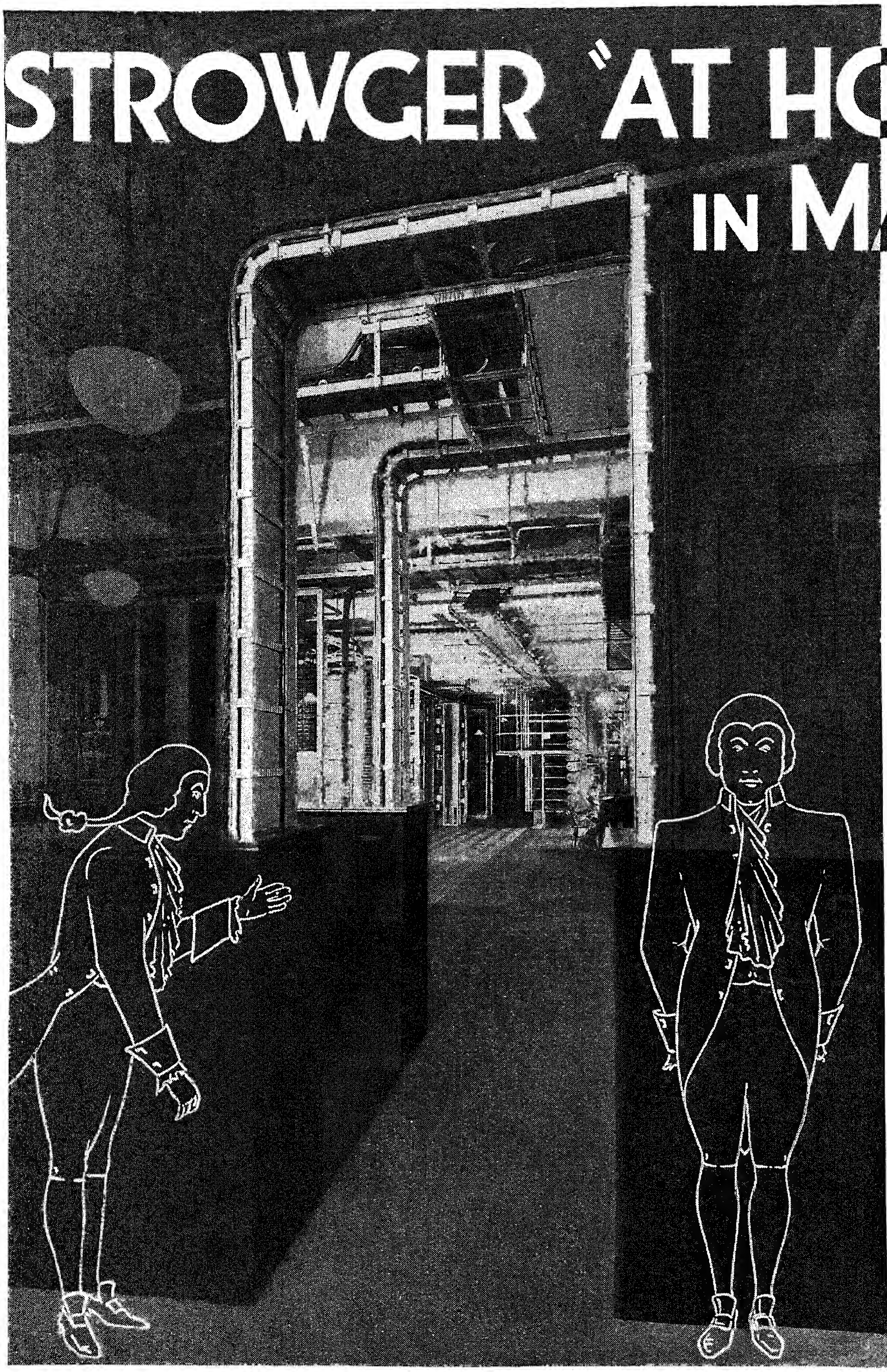

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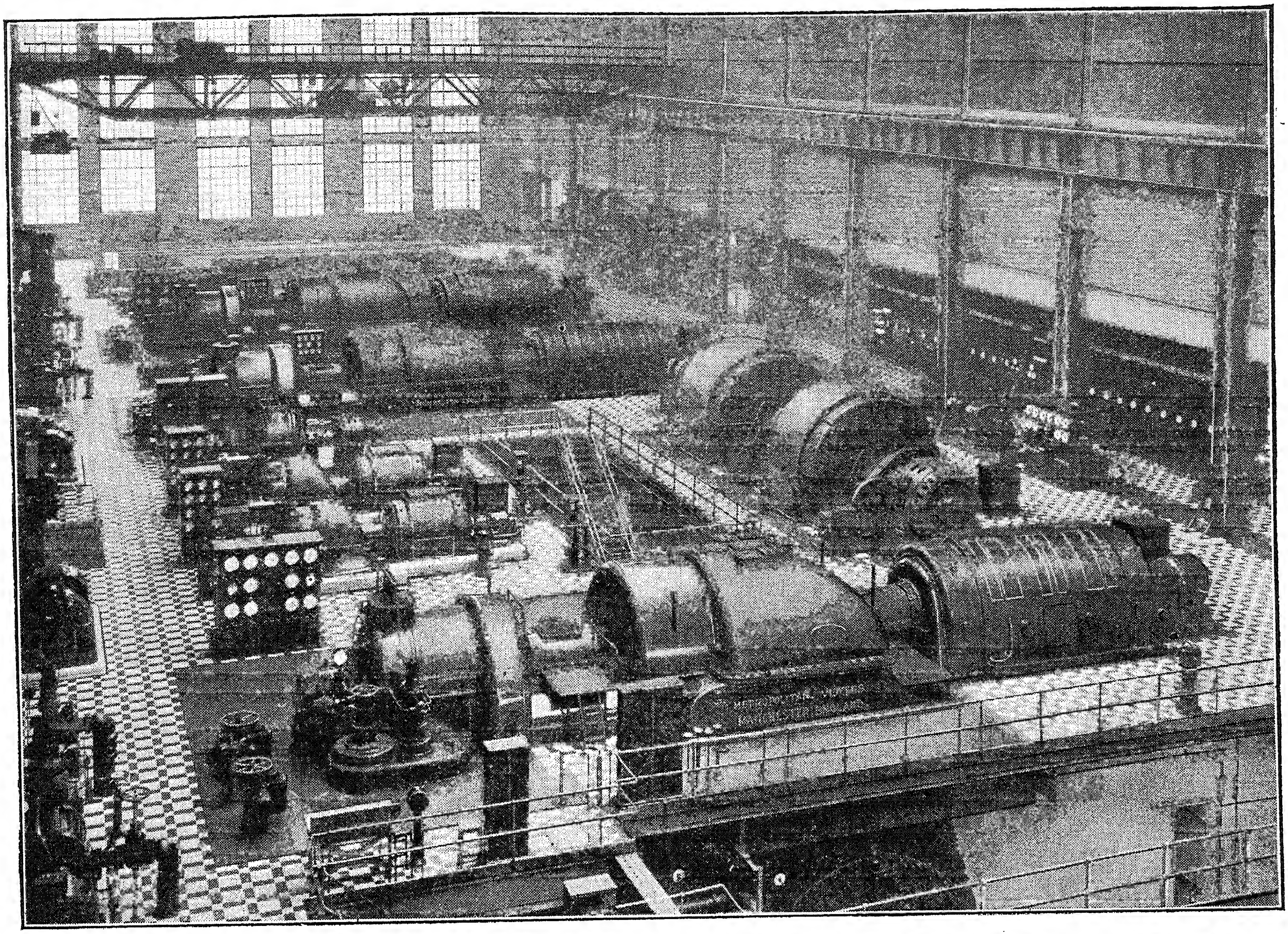

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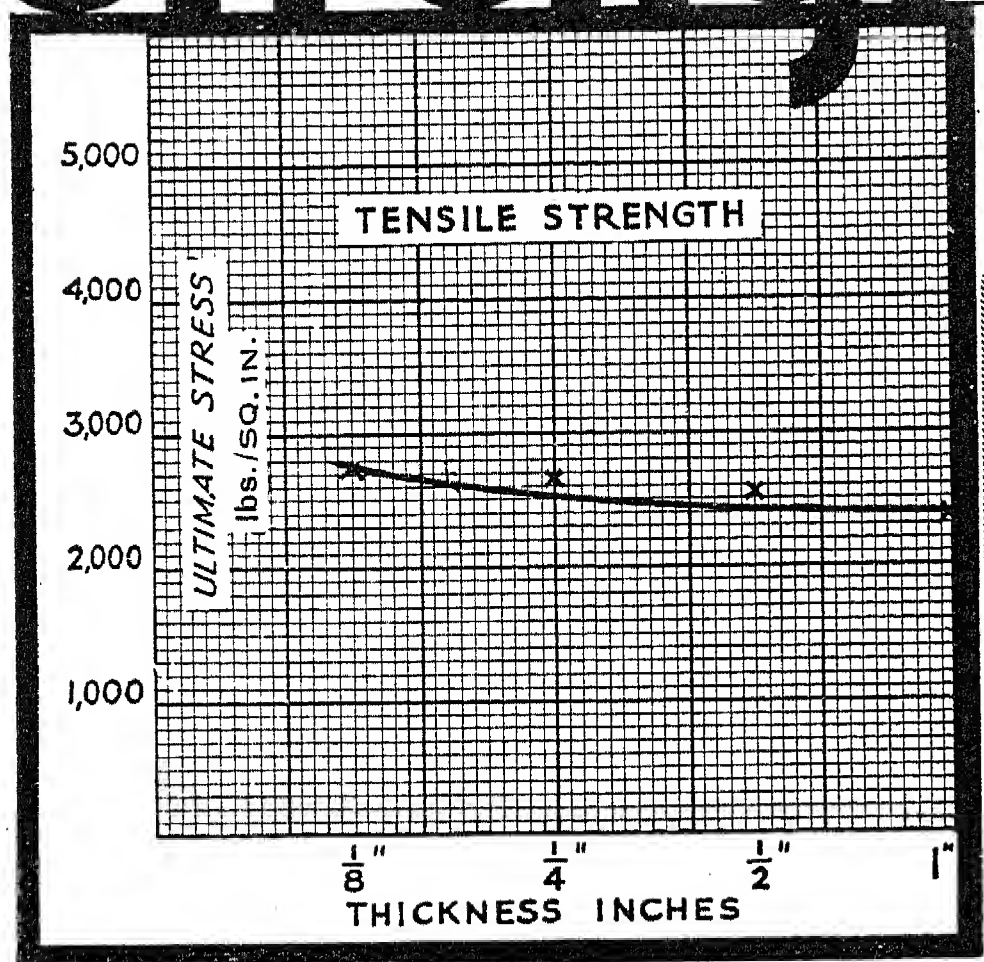

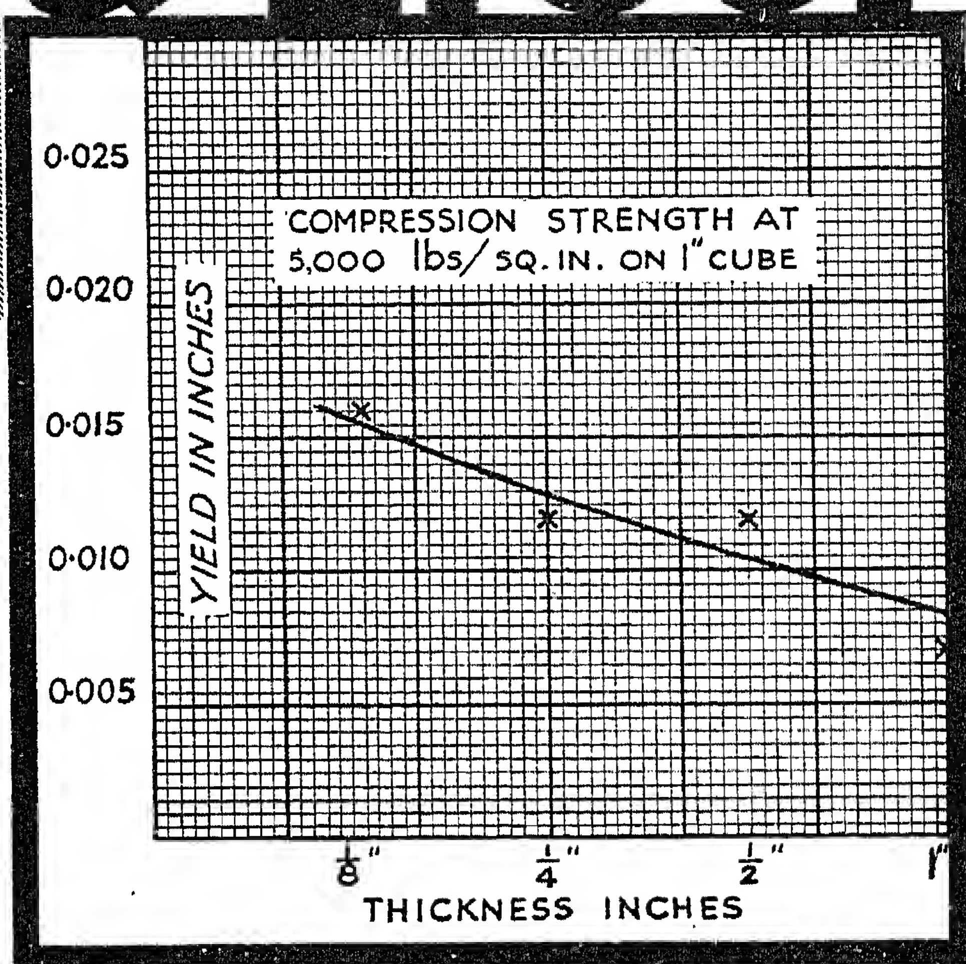

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½ in.	2,000,000	24° C.	2,000,000	22° C.
¼ in.	14,000,000	24° C.	14,000,000	22° C.
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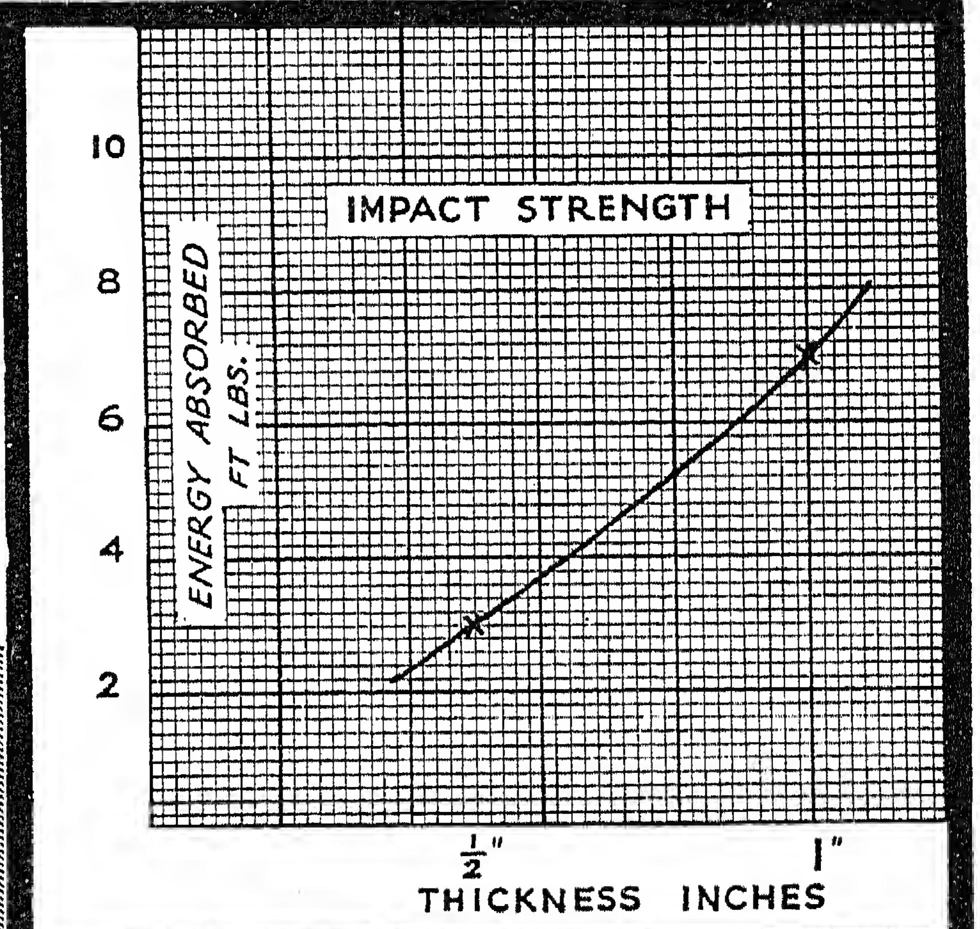

WATER ABSORPTION

Nominal Thickness of Sample	Increase in Weight after 48 Hours' Immersion in Water—Per cent.	Temperature
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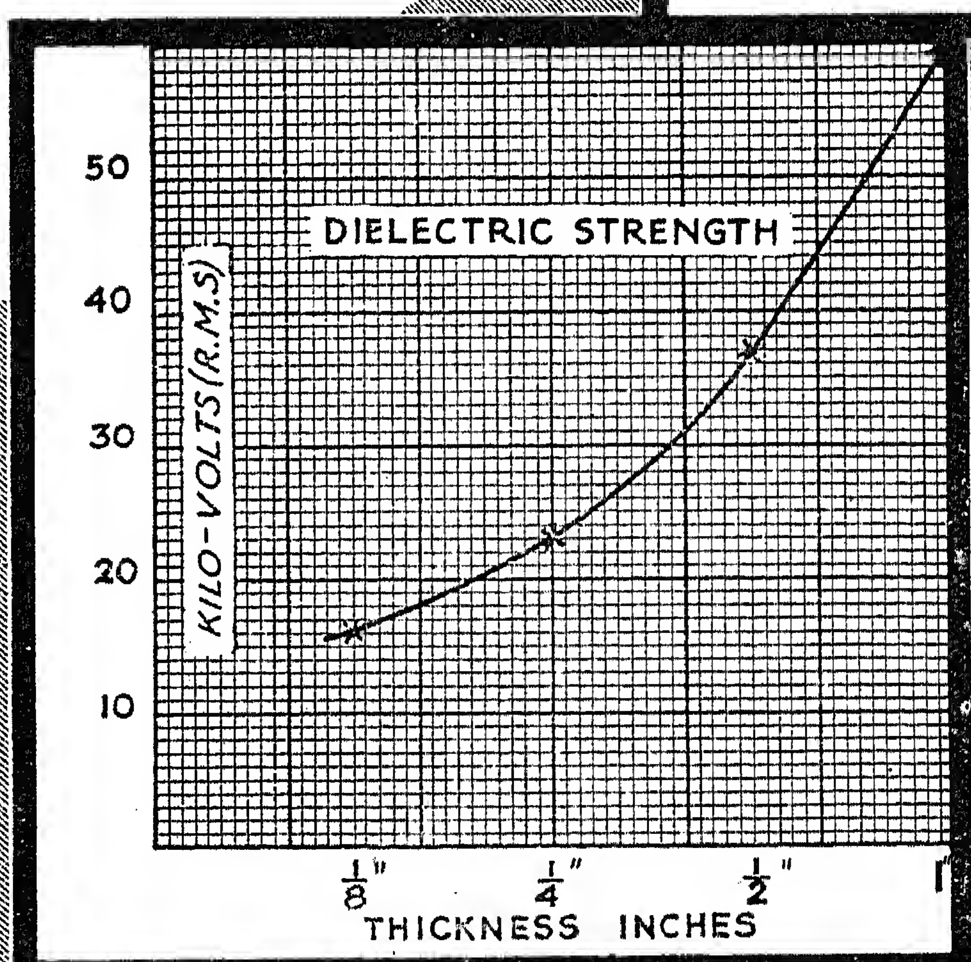
Note:—The sign × indicates that failure took place while the voltage was being increased to the next higher value.



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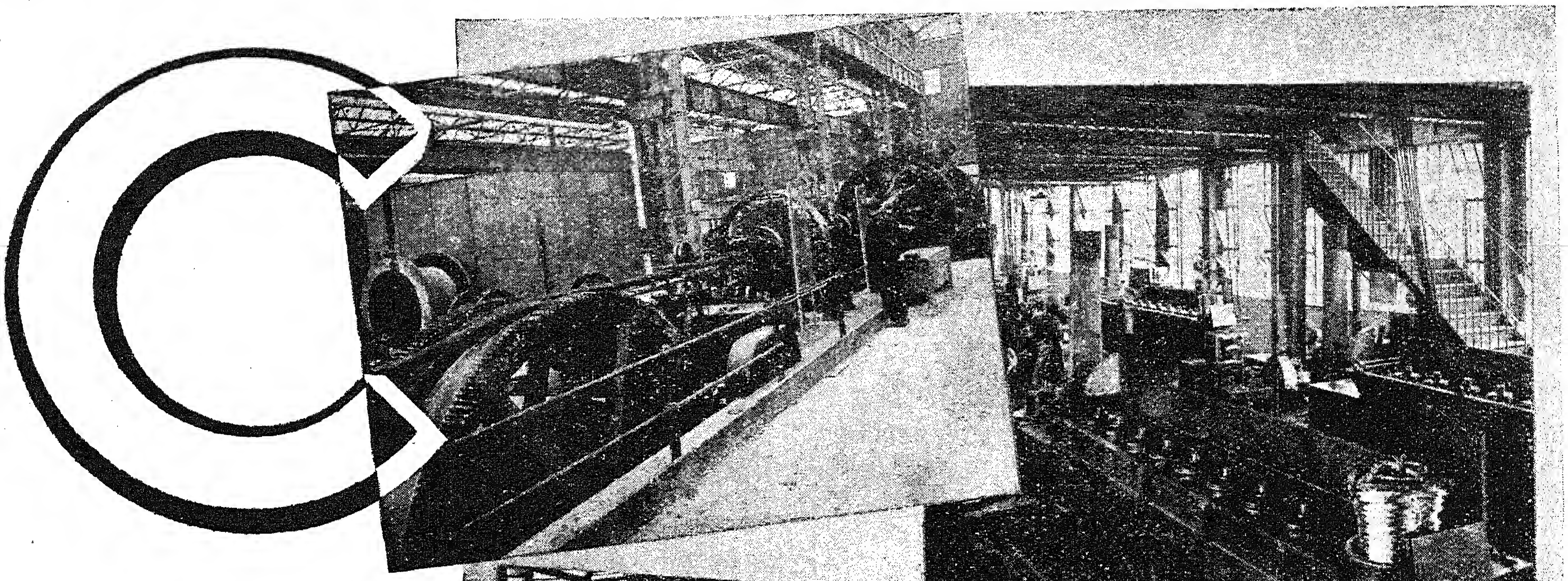

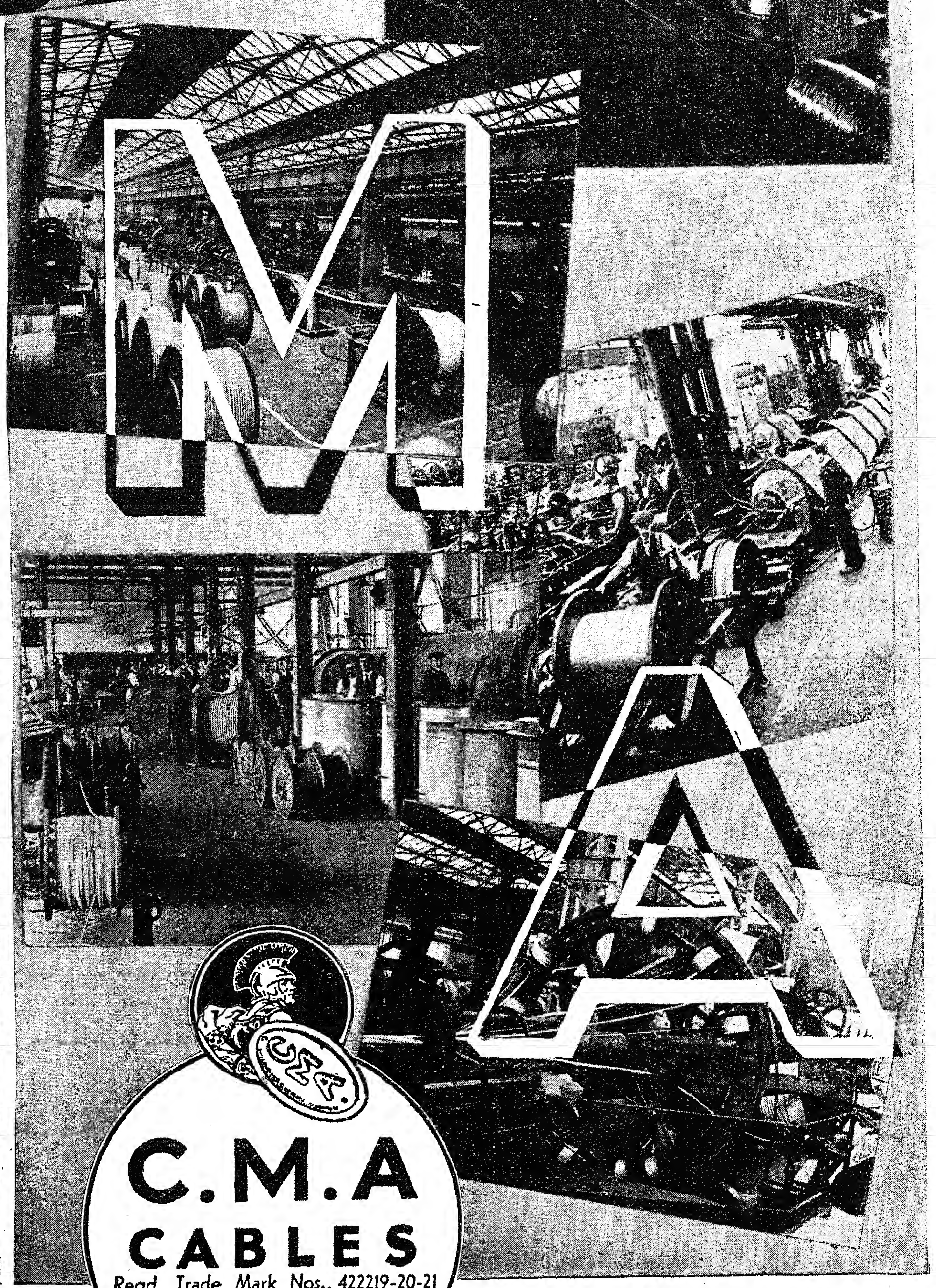

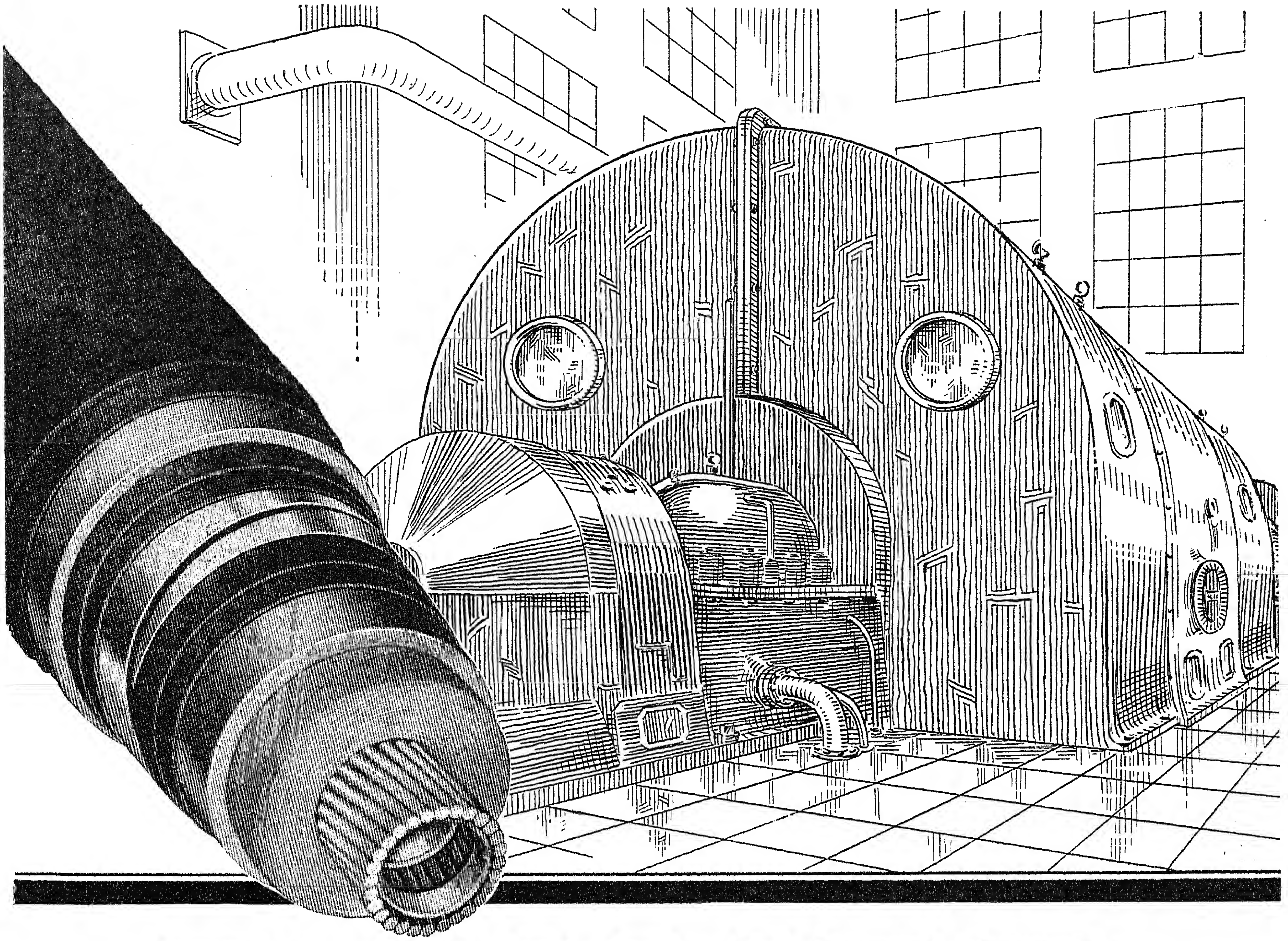

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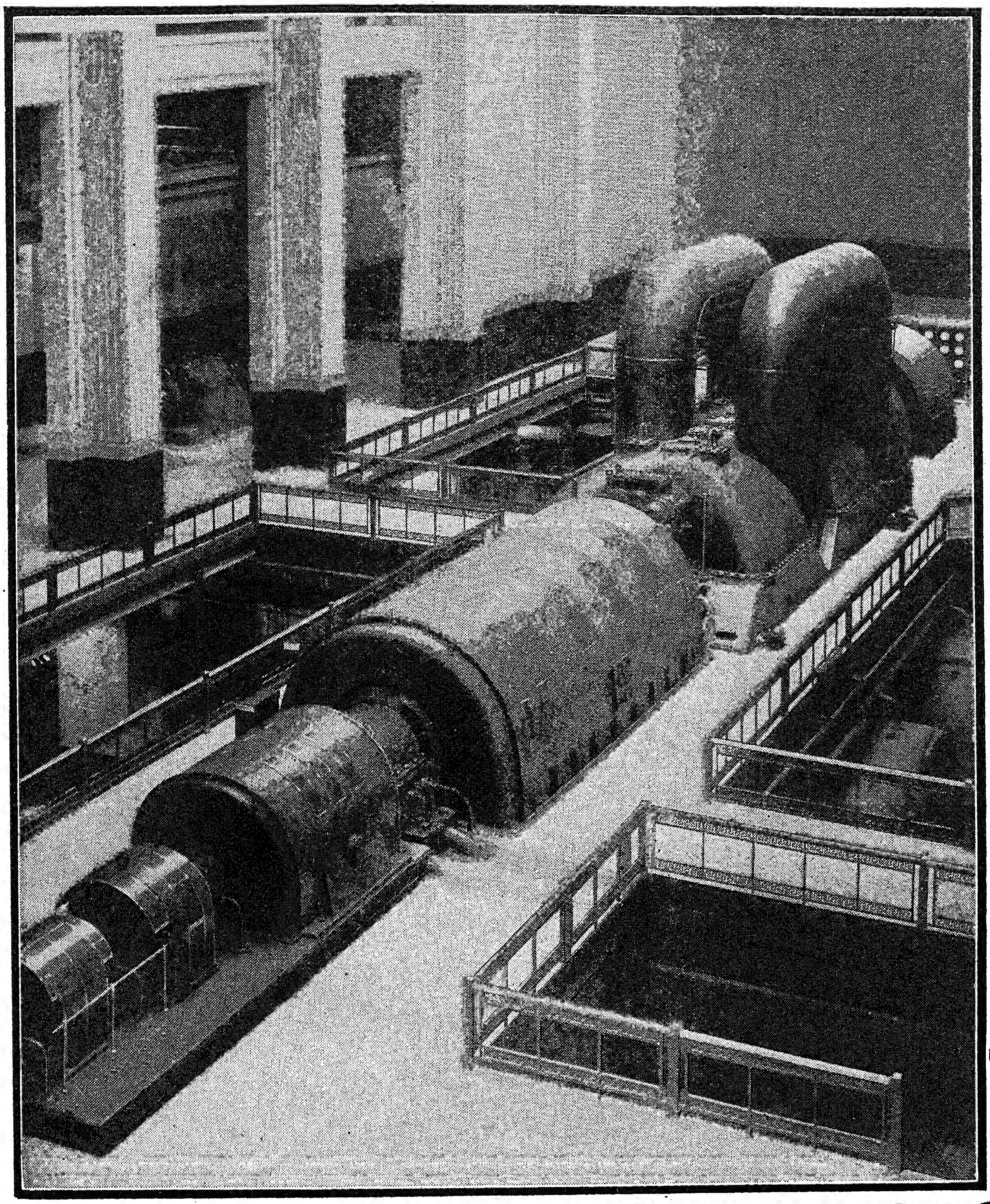

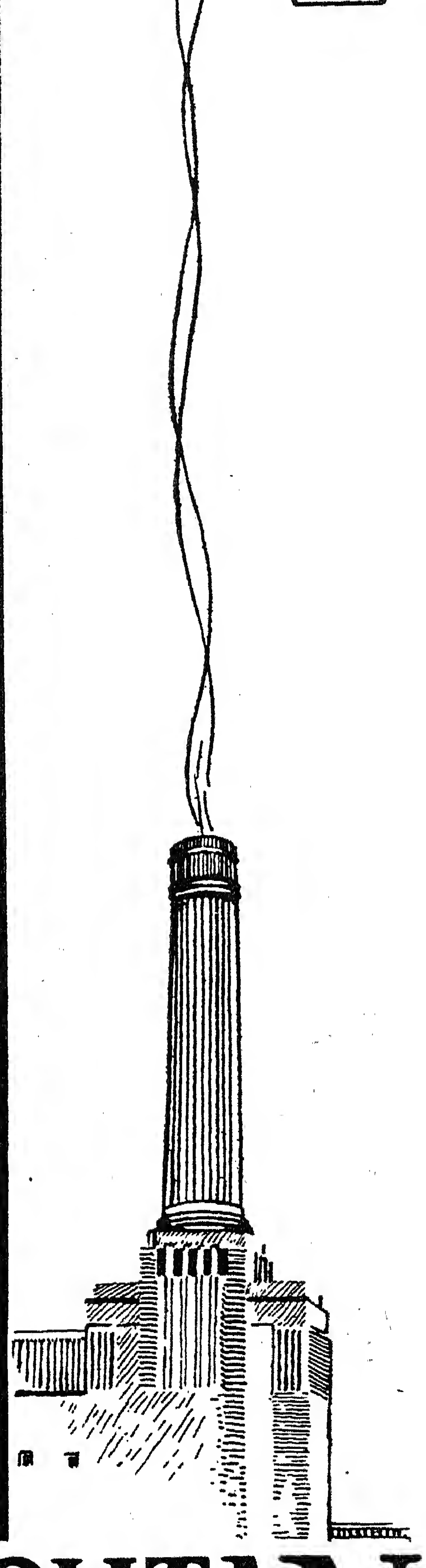

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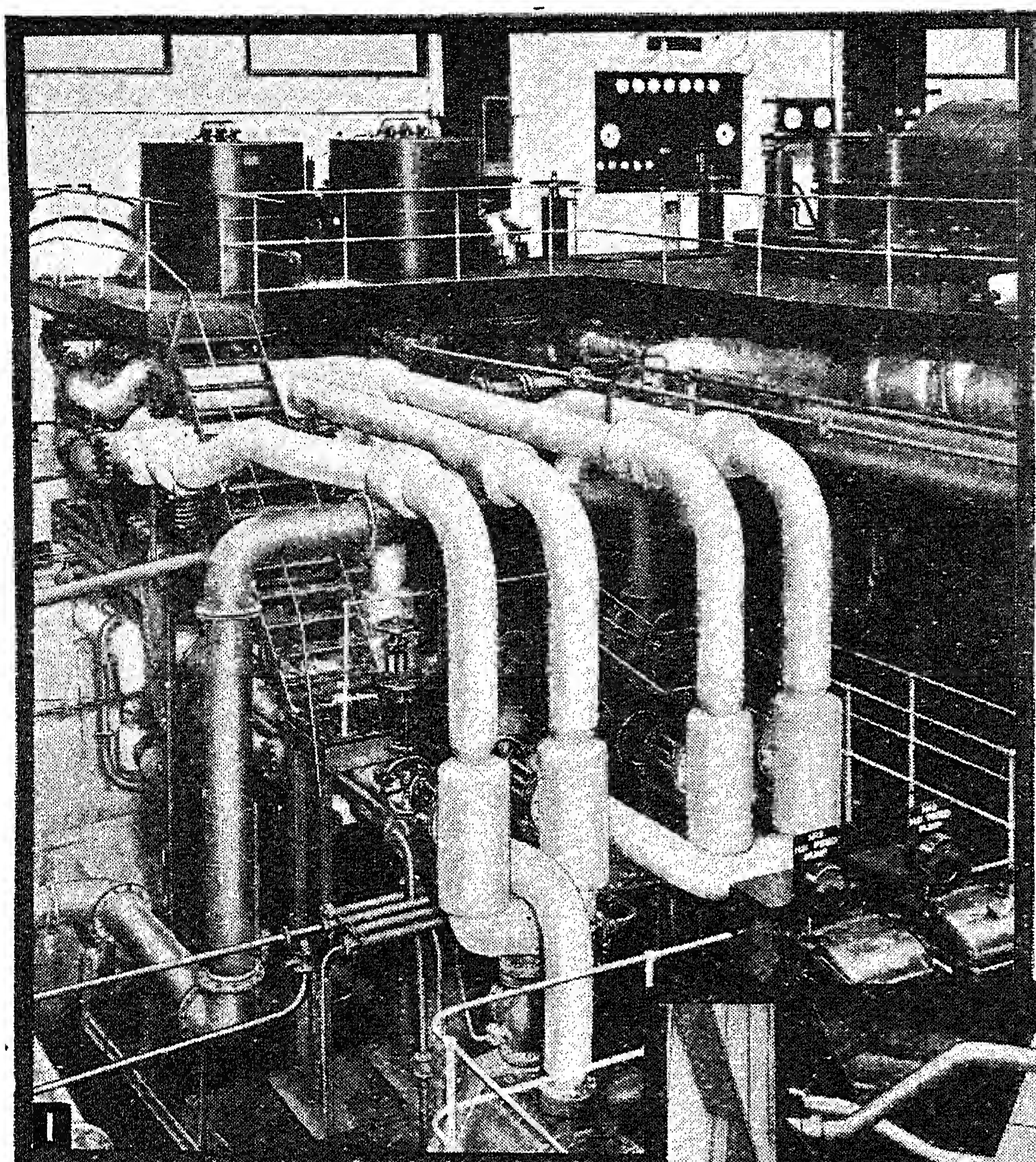
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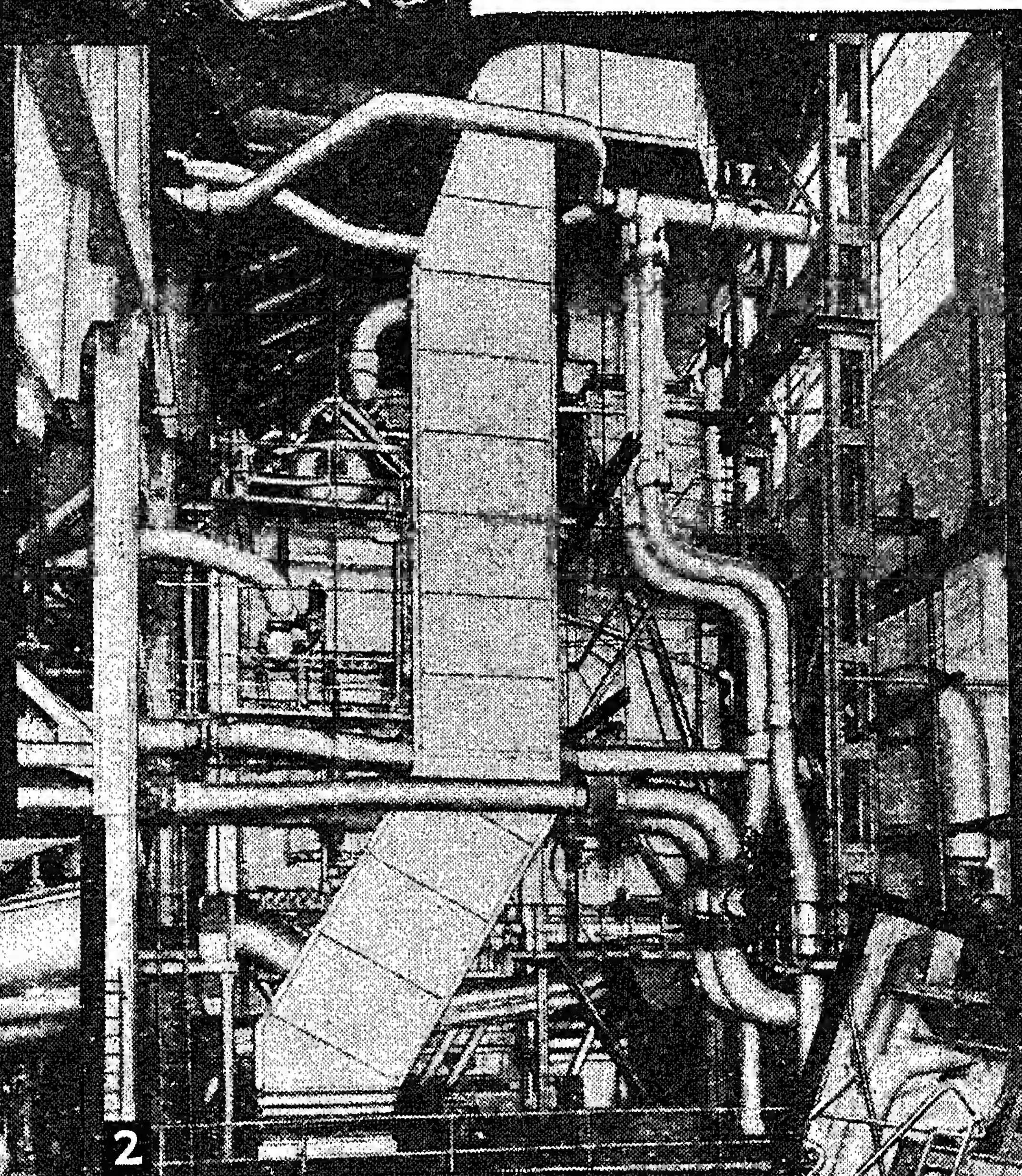
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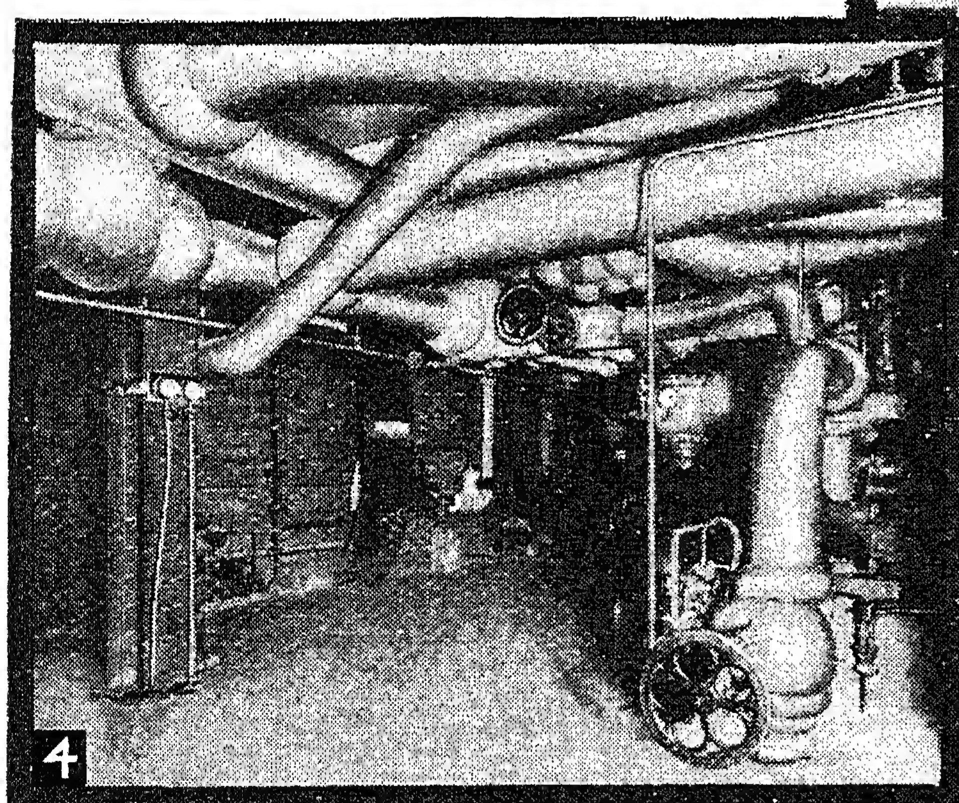
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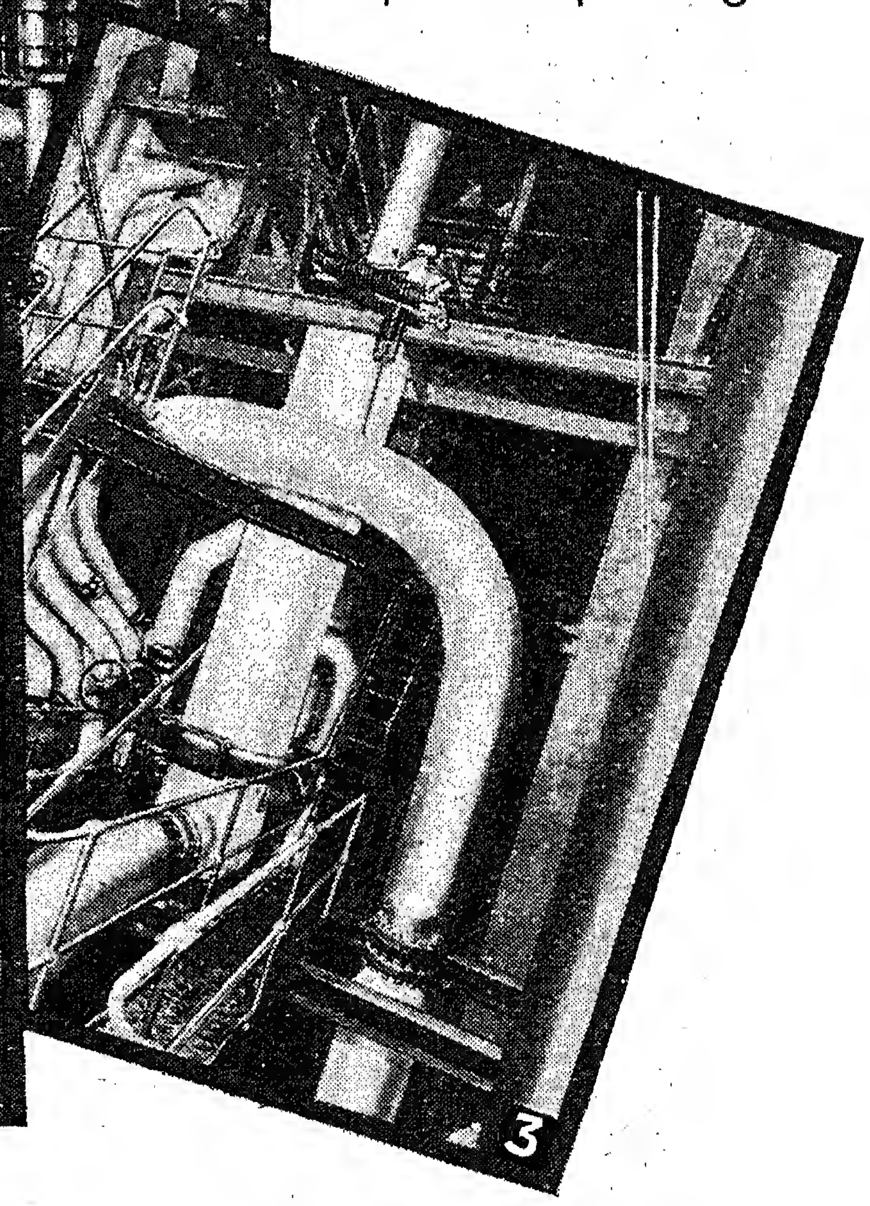
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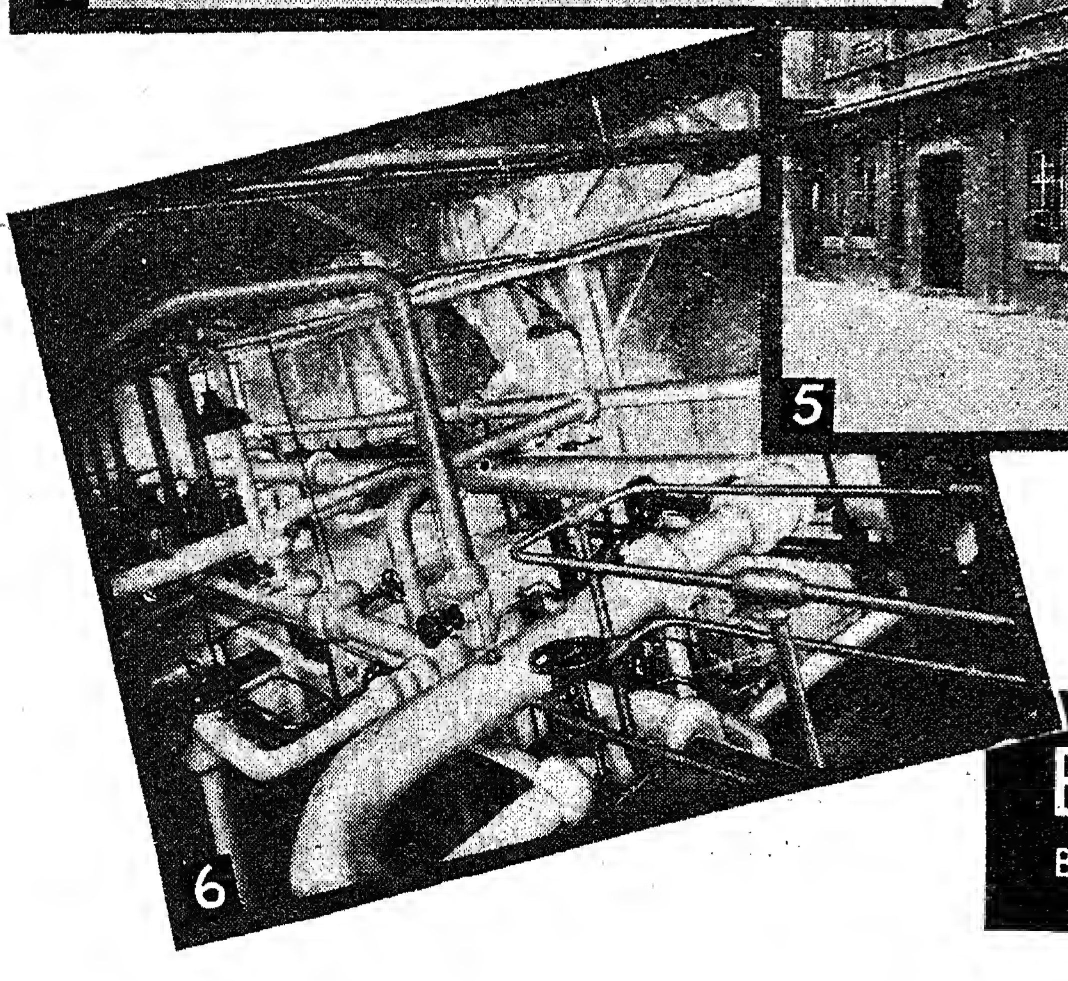
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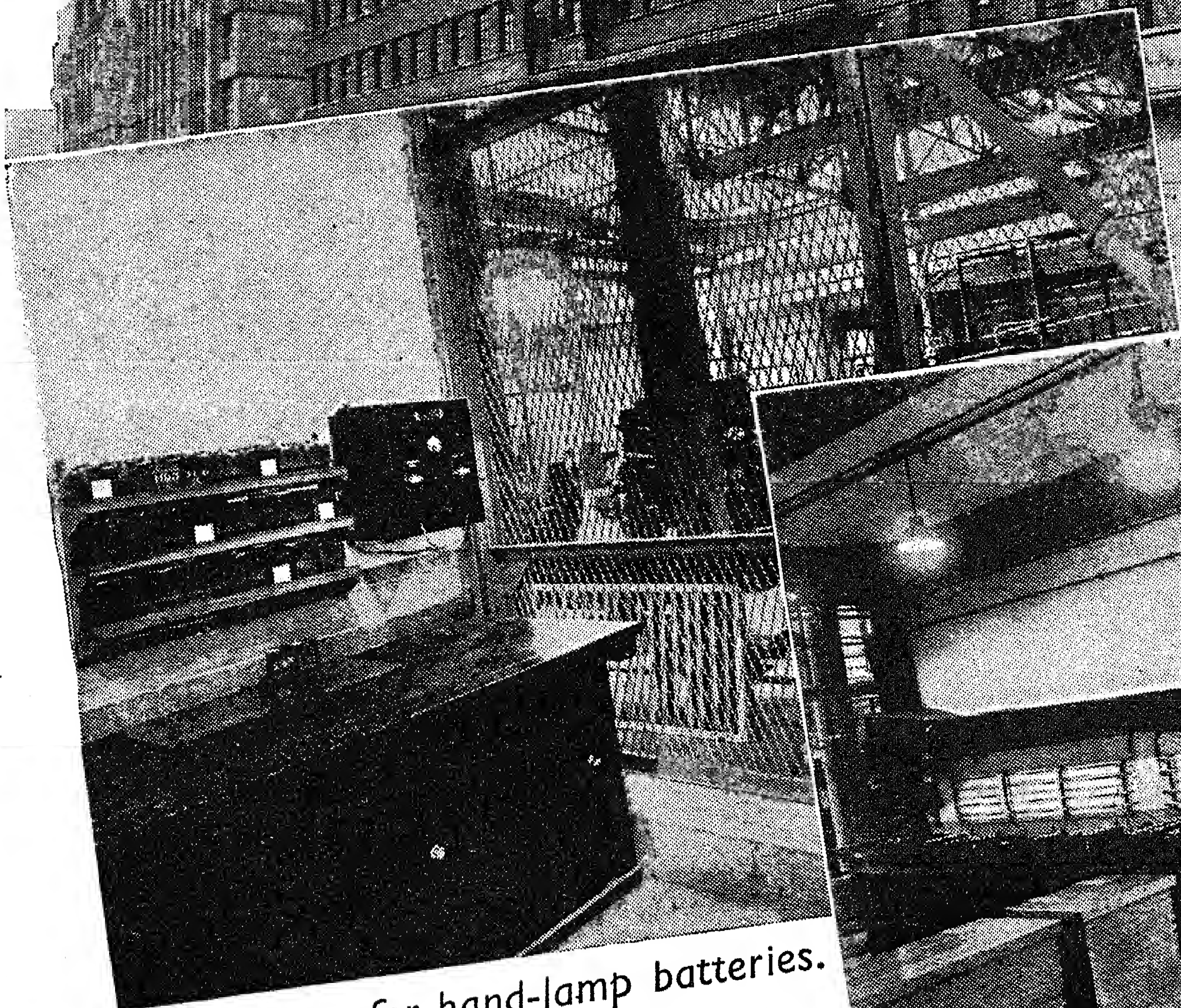

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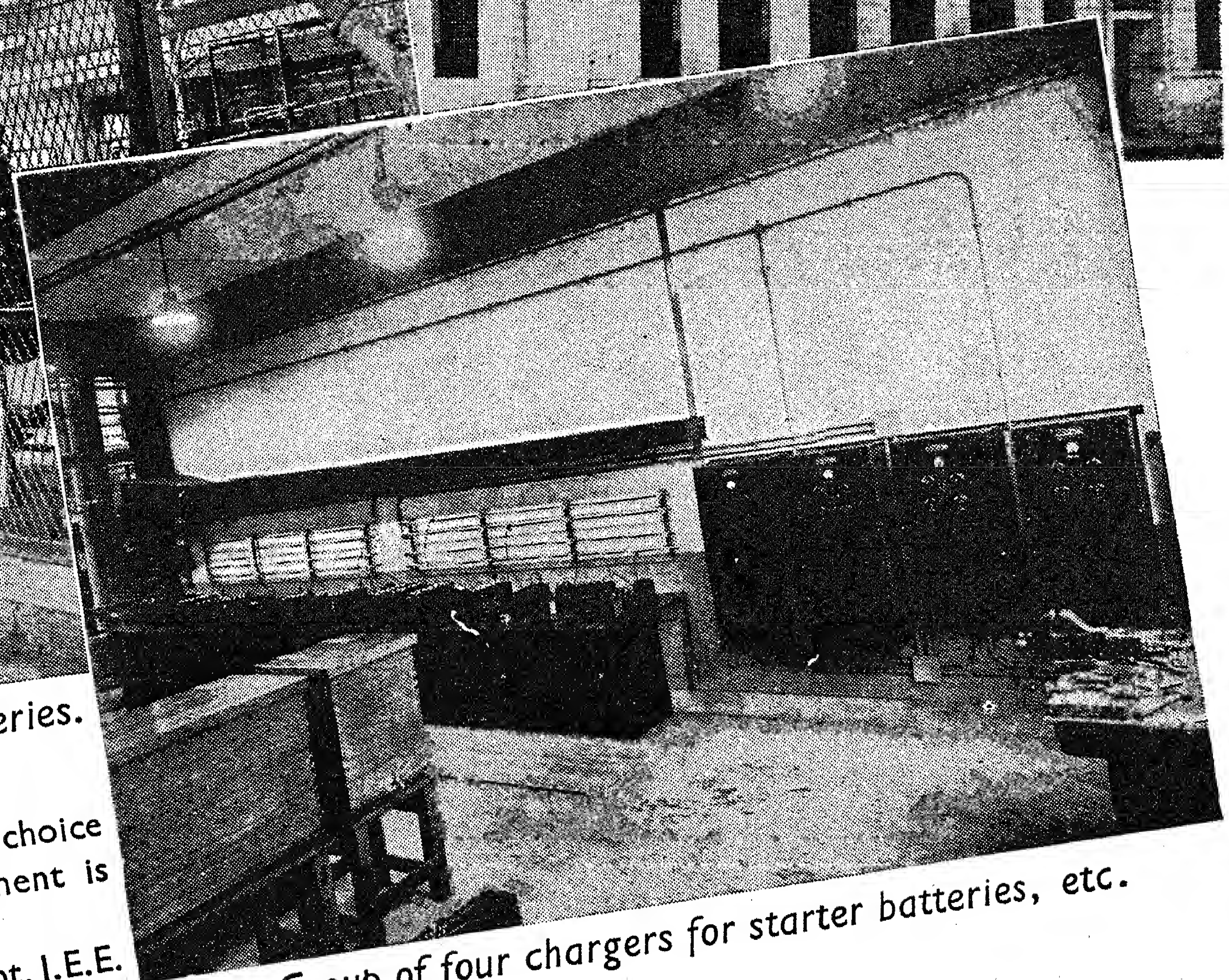

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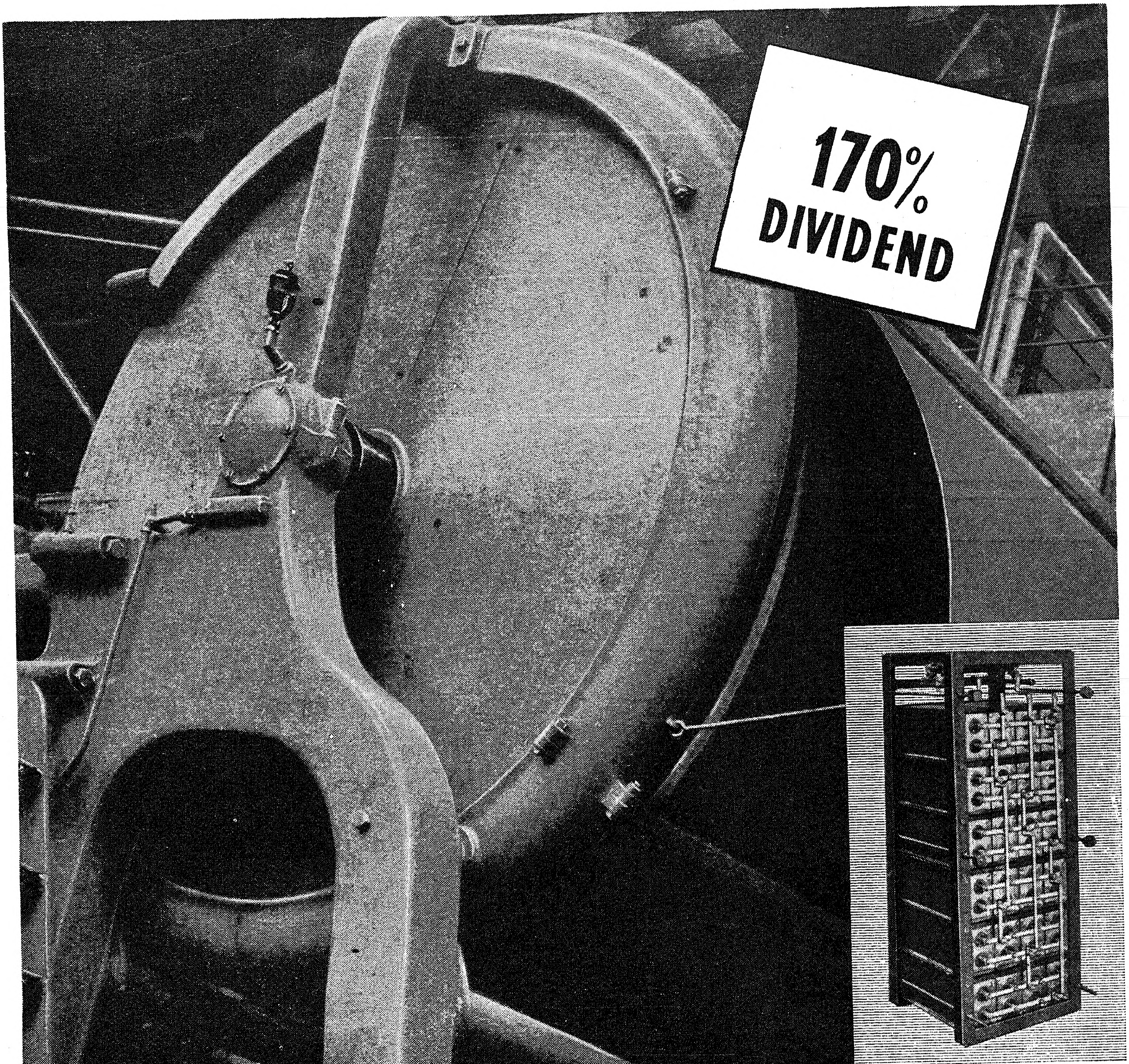
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